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A NEW SYSTEM OF SHORT WAVE AMPLIFICATION*

By
EDWIN H. ARMSTRONG
(COLUMBIA UNIVERSITY, NEW YORK)

The problem of receiving weak signals of short wave length in a practical manner has become of great importance in recent years. This is especially true in connection with direction finding work where the receiver must respond to a very small fraction of the energy which can be picked up by a loop antenna.

The problem may be summed up in the following words:—to construct a receiver for undamped, modulated continuous, and damped oscillations which is substantially equally sensitive over a range of wave lengths from 50 to 600 meters, which is capable of rapid adjustment from one wave to another, and which does not distort or lose any characteristic note or tone inherent in the transmitter.

It is, of course, obvious that some form of amplification must be used, but a study of the various known methods soon convinces one that a satisfactory solution cannot be obtained by any direct method. In the interests of completeness, we will consider the three well-known direct means which might possibly be employed, and examine the limitations which apply to each. These three methods are:—

(1) Amplification of the audio frequency current after rectification;

(2) Amplification of the radio frequency current before rectification; and

(3) Application of the heterodyne principle to increase the efficiency of rectification.

Consider first the method of rectifying the radio frequency current and amplifying the resulting audio frequency current. Two limitations at once present themselves, one inherent in audio frequency amplifiers, and the other inherent in all known rectifiers. The limitation in the amplifier is the residual noise which makes it impractical to use effectively more than two stages of amplification. The second limitation lies in the characteristic of the detector or rectifier. All rectifiers have a characteristic such that the rectified or audio frequency current is roughly proportional to the square of the impressed radio frequency emf. Hence the efficiency of rectification becomes increasingly poorer the weaker the signal until a point is reached below which the detector practically ceases to respond.

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* Presented before THE INSTITUTE OF RADIO ENGINEERS, New York, December 3, 1919. Received by the Editor, January 12, 1920.

The second method of attack on the problem is the amplification of the received radio frequency currents before rectification to a point where they can be efficiently dealt with by the detector. This method is ideal on long waves, and various methods of inductance, resistance, and capacity couplings have been successfully used, but when the attempt is made to use the same methods of coupling on wave lengths below 600 meters, it results in complete failure. This is because the low capacity reactance existing between the various elements of the tubes causes them, in effect, to act as a short circuit around the coupling means and thereby prevents the establishment of a difference of potential in the external plate circuit. It is, of course, possible to eliminate the short-circuiting by tuning with a parallel inductance but this introduces a complication of adjustment which is highly objectionable and the tuning of all circuits also leads to difficulty with undesirable internal oscillations.

The third method which might be used is the heterodyne method to increase the efficiency of rectification. Great increase in signal strength is possible by means of this method, particularly where the signal is very weak, but there are certain reasons why it cannot be effectively used in practice at the present time. The chief reason in receiving continuous waves of short wave length is the instability of the beat tone which makes operations below 600 meters unsatisfactory. This disadvantage does not apply to the reception of spark signals but here the loss of the clear tone and its individuality offsets much of the gain due to increased signal strength. In the case of telephony the distortion which always results likewise offsets the gain in strength. It is, of course, undeniable that there are many special cases where the use of the heterodyne on short wave lengths is of the greatest advantage but the foregoing remarks apply to the broad field of commercial working where the practical aspects of the case greatly reduce the value of the amplification obtained by this method.

In spite of the great difficulties involved in a direct solution, great success was obtained by Round in England and Latour in France in the production of radio frequency amplifiers to cover effectively a range from 300 to 800 meters. This result was accomplished only by the most painstaking and careful experiment and it represents some of the very finest radio work carried out during the war. Round secured his solution by constructing tubes having an extremely small capacity without increase in internal resistance above normal values and coupling the tubes by means of transformers wound with very fine wire to keep down the capacity and very high resistance to prevent oscillation at the resonant frequency of the system. The effect of the high ratio of inductance to capacity and the high resistance of the winding is to flatten the resonance curve of the system and widen the range of response. Latour solved the problem by the use of iron core transformers wound with very fine wire, the iron serving the double purpose of increasing the ratio of inductance to capacity and introducing resistance into the system. Both these factors widen the range of response.

It is the purpose of this paper to describe a method of reception evolved at the Division of Research and Inspection of the Signal Corps, American Expeditionary Force, which solves the problem by means of an expedient. This expedient consists in reducing the frequency of the incoming signal to some predetermined super-audible frequency which can be readily amplified, passing this current thru an amplifier, and then detecting or rectifying the amplified current. The transform tion of the original radio frequency to the pre-determined value is best accomplished by means of the heterodyne and rectification, and the fundamental phenomena involved will be understood by reference to the diagram of Figure 1. Here *LC* represents the

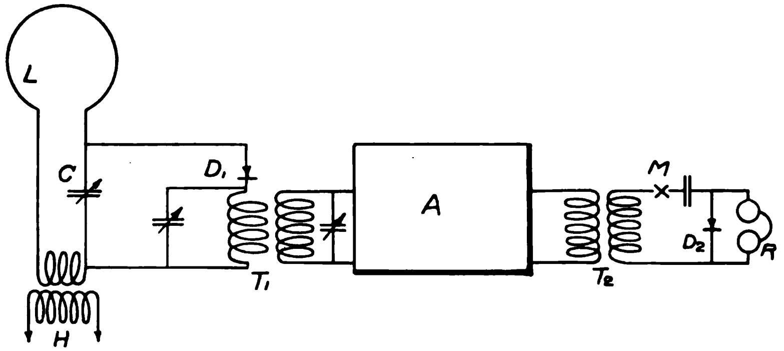

FIGURE 1

usual tuned receiving circuit, loop or otherwise, *H* a separate heterodyne, and D_1 a rectifier. *A* is a radio frequency amplifier designed to operate on some pre-determined frequency. This frequency may be any convenient frequency which is substantially above audibility. The amplifier is connected on its input side to the rectifier D_1, and on its output side to a second rectifier D_2 and a telephone or other receiver.

Suppose now that the frequency to be received is 3,000,000 cycles per second corresponding to a wave length of 100 meters and, for the sake of simplicity, that the incoming waves are undamped. Also, assume that the amplifier *A* has been designed for maximum efficiency at 100,000 cycles per second. The circuit *LC* is tuned to 3,000,000 cycles, and the heterodyne *H* is adjusted to either 3,100,000 or 2,900,000 cycles either of which will produce a beat frequency of 100,000 cycles per second. The combined currents of 3,000,000 and 3,100,000 (or 2,900,000) cycles are then rectified by the rectifier D_1 to produce in the primary of the transformer T_1 a direct current with a superimposed 100,000-cycle component. This 100,000-cycle current is then amplified to any desired degree by the amplifier *A* and detected or rectified by D_2. In order to get an audible tone where telephone reception is used some form of modulation or interruption must, of course, be employed in connection with this second rectification as the current in the output circuit of the amplifier is of a frequency above audibility. While this frequency is only 100,000 cycles and while it is therefore well within the range of practical heterodyning, its steadiness depends on the beats between 3,000,000 and 3,100,000 cycles per second and hence in any attempt to heterodyne it to audibility the same difficulties due to fluctuation would be encountered as in heterodyning the original radio frequency to audibility. However, the inability to use the heterodyne on the second rectification is not of great importance because the amplitude of the signal to be rectified is large and hence the difference (as far as signal strength in the telephone is concerned) between heterodyne and modulated reception is not great.

It is important to note here that the value of the heterodyne current in the first rectifier should always be kept at the optimum value in order to ensure the carrying out of the first rectification at the point of maximum efficiency. This adjustment, however, is not a critical one, and, once made, it is seldom necessary to change it. The amplifier *A* may be made selective and highly regenerative if so desired, and some very great increases in the selectivity of the system as a whole can be secured. Figure 2 illustrates the principle involved. This arrangement is substantially the same as Figure 1 except that the primary and secondary coils of the transformer T_1 are tuned by means of condensers as shown and the coupling between them is reduced to the proper value to insure sharp tuning. This system of

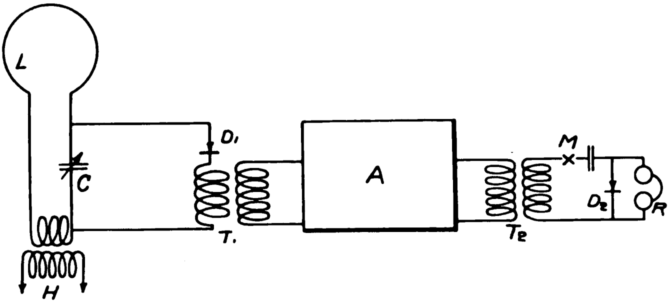

FIGURE 2

connection has all the advantages of tuning to the differential frequency in the manner well known in the art and an additional one due to the fact that since it is above audibility the musical character of atmospheric disturbances so troublesome in audio frequency tuning, does not appear.

So far, the reception of undamped waves only has been considered, but this method of amplification is applicable also to the reception of damped wave telegraphy and to telephony with practically equal efficiency and without distortion of any characteristics of tone. It is somewhat difficult to understand this, particularly in the case of the reception of spark signals as in all previous experience the heterodyning of a spark signal has resulted in the loss of the note, whereas in the present case the individuality between stations is more marked even than on a crystal rectifier.

This is the most interesting point in the operation of the system and the reason will be understood from the following analysis:

In heterodyning, the efficiency of rectification of the signaling current depends on its phase relation with the local current. If the two currents are either in phase or 180° out of phase the efficiency of rectification is a maximum; if 90° out of phase a minimum. In ordinary heterodyning, the initial phase difference depends on the time of sparking at the transmitter and hence this initial phase difference will be different for each wave train. As the frequency of the two currents are substantially the same, and as the duration of a wave train is short compared to the time necessary to produce a complete beat at an audible frequency, this initial phase difference is maintained thruout the wave train. Hence, the different wave trains are rectified with varying efficiency, the telephone current becomes irregular, and a rough or hissing tone results.

In the present method of heterodyning, the beat frequency is high so that several beats per wave train are produced. As a consequence, the phase angle between the signaling and local currents varies thru several cycles and the initial phase difference becomes a matter of minor importance. The number of beats which actually occur in practice depends on the beat frequency, the damping of the incoming wave, and the damping of the receiving circuit. As the damping of the receiving circuit is almost invariably much less than the damping of the incoming wave, it is the determining factor. In any practical case, however, where the beat frequency is kept above 20,000 cycles per second there is a sufficient number of beats to minimize the initial phase differences and maintain the characteristic tone.

The phenomena which occur in the reception of modulated continuous wave telegraphy and telephony are substantially a combination of those explained in the cases of undamped and damped wave reception. The adjustments are made in the same manner as for damped waves and the only precaution necessary in the reception of telephony is to damp the amplifier circuits somewhat to prevent distortion of the speech by excessive resonance.

The general arrangement found most suitable for practical working is shown in Figure 3. Both rectifications are carried out by three-element vacuum tubes. The amplifier here shown is resistance coupled, although any form of coupling may be used. The tuned circuits LC and L_2C_2 are preferably adjusted to some frequency between 50,000 and 100,000 cycles. The circuit LC may be made regenerative, if so desired, by any form of reactive coupling, but the practicability of this depends largely on the amount of time which is available for making adjustments.

In the diagram of Figure 3, only two stages of radio frequency amplification are shown, but at least four and preferably six should be used to get the maximum advantage of this method.

This is because the transformation of frequency is accomplished only by a certain loss so that something between one and two stages of amplification is required before this is overcome and it is possible to realize a gain. In this figure a separate heterodyne is shown, and it will generally be necessary to use it on account of the mistuning which is involved in the use of the self heterodyne This mistuning is considerable on 600 meters but on the shorter waves it is possible to use the self heterodyne method with equal efficiency as far as signal strength is concerned and a great gain in simplicity, as adjustments have been reduced to the minimum of a single one.

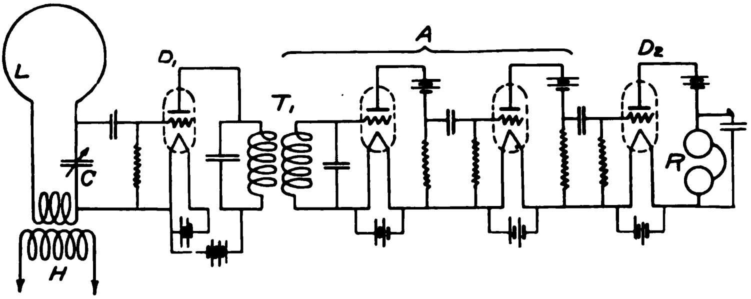

FIGURE 3

It may be observed here that this method is not limited to one transformation of frequency with one subsequent amplification. If the frequency to be received is 5,000,000 cycles this may be stepped down to 500,000 cycles, amplified, stepped down again to 50,000 cycles, re-amplified and detected. The great advantage of this method of amplification is that the tendency to oscillate due to the reaction between the output of the amplifier and the input is eliminated as the frequencies are widely different. The only reaction which can take place is in each individual amplifier. Hence, the process of extreme amplification is best carried out in stages of several frequencies, the amplification on each frequency being carried as far as possible without loss of stability. As soon as the limit of stable operation is approached, no further amplification should be attempted until the frequency has been changed.

The foregoing descriptions and explanations do not pretend to any save a most superficial treatment of the phenomena present in this method of reception. Lack of time has prevented a careful study and quantitative date only of the roughest sort has been obtained. Sufficient work has been done, however, to demonstrate the value of the method particularly in the case of modulated continuous wave telegraphy and telephony. In this field neither the amplification nor the selectivity can be equalled by any direct method.

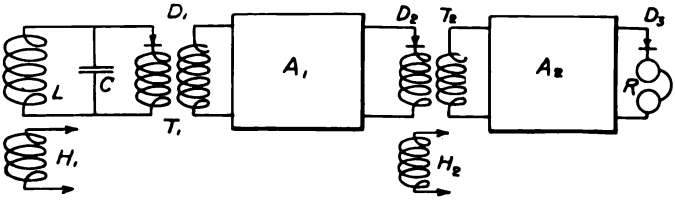

FIGURE 4

The practical results which have been obtained may perhaps be of interest. With a ten-turn, three-foot (1 meter) loop antenna and an amplifier consisting of six stages, resistence coupled, making a total of eight tubes, the night signals of ships working with the Florida and Gulf stations are loudly received. The night signals of amateur stations in the Middle West are regularly received as are also the signals of stations in the Gulf States. The general arrangement of the apparatus used is shown in Figures 5 and 6 which illustrate the scheme of connections of the frequency transformer and amplifier respectively. Four stages of amplification only are shown but six were actually used.

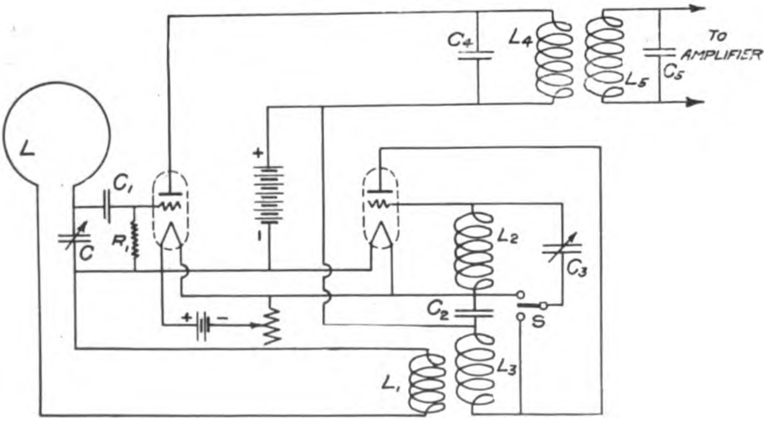

FIGURE 5

It is beyond question much more efficient to use some form of inductive coupling since the amplifier is intended to operate on only one frequency and the use of a resistance coupled amplifier is not recommended where one of the former type is available.

The new practice of this method involves the use of many known inventions, but in connection with the production of a superaudible frequency by heterodyning I wish to make due acknowledgment to the work of Meissner, Round, and Levy, which is now of record. The application of the principle to the reception of short waves is, I believe, new and it is for this reason that this paper is presented.

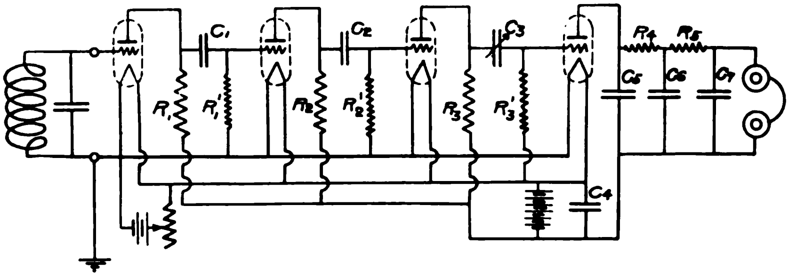

FIGURE 6

While the fundamental idea of this method of reception is relatively simple, the production of the present form of the apparatus was a task of the greatest difficulty for reasons known only too well to those familiar with multi-stage amplifiers; and to Lieutenant W. A. MacDonald, Master Signal Electricians J. Pressby and H. W. Lewis, and Sergeant H. Houck, all of the Division of Research and Inspection Signal Corps A. E. F., I wish to give full credit for its accomplishment.

Hartley Research Laboratory,
Columbia University, New York City.

SUMMARY: The various possible known methods of amplifying incoming signals of very short wave length (below 600 meters) are described and their limitations considered.

The new method then described consists (for continuous wave reception) of the following steps:—

1. Heterodyning, with the production of a beat frequency which is itself a *radio* frequency (for example, 100,000 cycles per second).
2. Rectification of the beat current.
3. Amplification at the beat radio frequency, preferably by a tuned amplifier.
4. Audio frequency modulation of the amplified current.
5. Rectification of the modulated current.

For reception of damped wave or radiophone signals, step 4 is omitted. It is shown that in this case the quality (characteristic tone) of the incoming signals is preserved.

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DISCUSSION

A. S. Blatterman (by letter received December 17, 1919): Up to the present time it has been found very difficult to amplify radio signals having oscillation frequencies of the order of 1,000,000 cycles and practically impossible to do so when the frequency reaches 3,000,000 cycles or greater. The difficulties are attributable chiefly to capacity effects in the vacuum tubes as well as in the wiring, and also because it is a fairly difficult problem to build a really satisfactory coupling impedance or transformer to connect up the output of one tube with the input side of the tube next in the series when the frequency is very high. Movements of the hands of the operator or of his body near the apparatus in such cases cause extremely minute changes in capacity which are, nevertheless, sufficient to cause changes in tuning that seriously reduce the received signals.

Moreover, it is seldom, if ever, that a radio receiver can be designed for a single frequency. Both at the extremely high frequencies just mentioned as well as for the lower frequencies corresponding to long wave lengths, it is practically always necessary to arrange for reception over a more or less limited range of wave lengths and this requirement has also been a very serious factor in the design of all radio frequency amplifiers up to the present time. At radio frequencies it is possible, convenient and desirable to use tuned transformers for the couplings between successive stages; but because of the necessity for making the amplifier responsive over a large number of wave lengths the tuning of the transformers must be relatively broad. This involves the arbitrary introduction of resistance into the circuits and the loss in efficiency that results seriously reduces the overall amplification.

Major Armstrong has met the above difficulties in the way of radio frequency amplification by a method which in principle is as simple as it is highly ingenious, and, at least for the amplification of excessively short wave lengths, appears to be a satisfactory solution of the problem in hand. The principle can, as is stated by Major Armstrong, be applied to damped wave and continuous wave telegraphy and to telephony. For receiving continuous waves a second heterodyne, either self or separate, must be brought to act on the second detector or else some form of chopper must be used. For very short waves of the order of 50 meters, it is possible to make a self-heterodyne of the first tube and thus avoid the extra adjustments and apparatus required by a separate local oscillator. In this case it is advisable to use as low a beat frequency as possible in order not to necessitate too much mistuning, and to design the amplifier circuits accordingly. The question, however, of selecting the proper super-audible beat frequency and the actions involved in the performance of these circuits are not as simple perhaps as Major Armstrong may have led some of us to believe. Upon closer inspection it is found that certain limitations must be imposed upon the design, especially in application to the reception of spark and telephone signals, and it appears likely that the system cannot be used to advantage at all radio frequencies.

The following paragraphs may be of particular interest in connection with the opinion held by some that the present amplifier will tend toward returning spark radio systems to the favor accorded them before the advantages of continuous waves were so fully appreciated and utilized.

GENERAL THEORETICAL CONSIDERATIONS

In the reception of *continuous waves* by the method under consideration the actions involved are relatively simple. The interference of the incoming signal oscillation with that produced locally results in a beat frequency which is almost truly sinusoidal and makes the design of the coupling transformers a very satisfactory proposition with the possibility of securing maximum amplification through sharp tuning and accurate resonance adjustments. In this case also, it is quite immaterial, as far as the operation of the amplifier is concerned, whether the super-audible beat frequency used is adjusted to something of the order of 100,000 or 200,000 cycles or whether it is set at a low value of say 15,000 cycles.

For receiving spark signals, however, and for telephony the situation is somewhat different. Special precautions must be taken in order to avoid distortion effects, and the selection of proper value of the super-audible beat frequency is important.

Figure 1 is supposed to represent trains of damped voltage oscillations such as are produced at the detector of a receiving circuit by a spark transmitter. The successive groups of oscillations recur at tonal frequencies, each group being the result of a discharge at the spark gap of the transmitter. The mathematical expression for such a train of oscillations may be written as follows:

$$[V+V_1 sin\,(pt+\phi_1)+V_2 sin\,(2\,pt+\phi_2)+V_3 sin\,(3\,pt+\phi_3)+ \cdots V_n sin\,(n\,pt+\phi_n)]\,sin\,\omega_1 t \qquad (1)$$

wherein the bracketed expression is the equation of the envelope curve bounding the amplitude of the radio frequency oscillations, expressed in the form of a Fourier's series, and the last term, $sin\,\omega_1 t$, refers to the radio frequency oscillation of periodicity ω_1 which is to be considered as an oscillation modulated at audible frequency according to the envelope curve just mentioned.

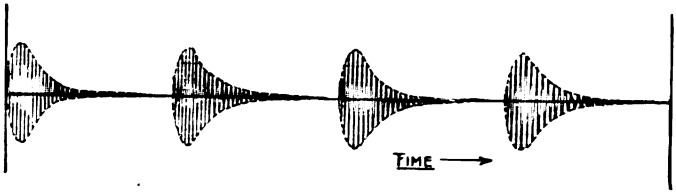

FIGURE 1

The envelope contains a fundamental frequency corresponding to p and all the harmonics $2\,p$, $3\,p$, $4\,p$, $\cdots$ $n\,p$ characteristic of the spark frequency and of the decrements of the transmitter and receiver. Thus, ordinarily the periodicity p would correspond to a 500- or 1000-cycle spark and the harmonics may run to the 10th or 20th before their amplitudes are small enough to make them negligible. V_1, V_2, V_3, $\cdots$ V_n designate respectively the amplitudes of the fundamental and the various harmonics. ϕ_1, ϕ_2, $\cdots$ ϕ_n and so on represent their phases.

The voltage produced by the local oscillation for heterodyning is

$$V'\,cos\,(\omega_2 t+\theta) \qquad (2)$$

The total or resultant voltage acting on the first detector at every instant is therefore given by the sum of expressions (1) and (2). This can be written in the following form

$$\begin{aligned}
&V_1\left[\cos\frac{(\omega_1-\omega_2-p)\,t+(\phi_1-\theta)}{2}\cos\frac{(\omega_1+\omega_2-p)\,t+(\phi_1+\theta)}{2}\right.\\
&\qquad\left.-\sin\frac{(\omega_1-\omega_2+p)\,t+(\phi_1-\theta)}{2}\sin\frac{(\omega_1+\omega_2+p)\,t+(\phi_1+\theta)}{2}\right]\\
&+V_2\left[\cos\frac{(\omega_1-\omega_2-2p)t+(\phi_2-\theta)}{2}\cos\frac{(\omega_1+\omega_2-2p)t+(\phi_2+\theta)}{2}\right.\\
&\qquad\left.-\sin\frac{(\omega_1-\omega_2+2p)\,t+(\phi_2-\theta)}{2}\sin\frac{(\omega_1+\omega_2+2p)\,t+(\phi_2+\theta)}{2}\right]\\
&+V_3\left[\cos\frac{(\omega_1-\omega_2-3\,p)\,t+(\phi_3-\theta)}{2}\cos\frac{(\omega_1+\omega_2-3\,p)\,t+(\phi_3+\theta)}{2}\right.\\
&\qquad\left.-\sin\frac{(\omega_1-\omega_2+3\,p)\,t+(\phi_3-\theta)}{2}\sin\frac{(\omega_1+\omega_2+3\,p)\,t+(\phi_3+\theta)}{2}\right]\\
&+\\
&+V_n\left[\cos\frac{(\omega_1-\omega_2-n\,p)\,t+(\phi_n-\theta)}{2}\cos\frac{(\omega_1+\omega_2-np)t+(\phi_n+\theta)}{2}\right.\\
&\qquad\left.-\sin\frac{(\omega_1-\omega_2+n\,p)\,t+(\theta_n-\theta)}{2}\sin\frac{(\omega_1+\omega_2+n\,p)\,t+(\phi_n+\theta)}{2}\right]\\
&+V\sin\omega_1 t \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (3)
\end{aligned}$$

In each of the bracketed terms four different frequencies appear, namely,

$$\frac{\omega_1-\omega_2-k\,p}{4\pi}$$

$$\frac{\omega_1-\omega_2+k\,p}{4\pi}$$

$$\frac{\omega_1+\omega_2-k\,p}{4\pi}$$

$$\frac{\omega_1+\omega_2+k\,p}{4\pi}$$

k having the different values 1, 2, 3, 4, · · · n corresponding to the 1st, 2nd, 3rd, 4th, or nth bracket involving the 1st, 2nd, 3rd, or nth harmonic.

The explicit values of these frequencies depend principally upon the values ω_1 and ω_2 of the incoming and local radio frequencies and also to an increasing extent upon the periodicities $k\,p$, of the audio harmonic spark frequencies, for the higher harmonics. Relatively the four frequencies concerned may be of the same or very different orders of magnitude, and the two cases presented hereby involve important practical considerations in the design and use of the amplifier. The two different conditions may be treated separately under the headings (1) Short Wave Reception and (2) Long Wave Reception.

SHORT WAVE RECEPTION

The wave lengths to be considered here are of the order of 50 or 100 meters, or shorter. In this case ω_1 and ω_2 are both very large and of the four frequencies mentioned above the two involving the differences $\omega_1-\omega_2$ are considerably smaller than the two comprising the sums $\omega_1+\omega_2$. Thus, the two trigonometric products which appear in each of the bracket terms of (3) indicate a radio frequency voltage of frequency

$$\frac{\omega_1+\omega_2\pm k\,p}{4\pi}$$

modulated by a considerably lower, tho still super-audible, frequency, in the present amplifier, of value

$$\frac{\omega_1-\omega_2\pm k\,p}{4\pi}$$

The form of such a voltage wave for one of the trigonometric products is shown in Figure 2.

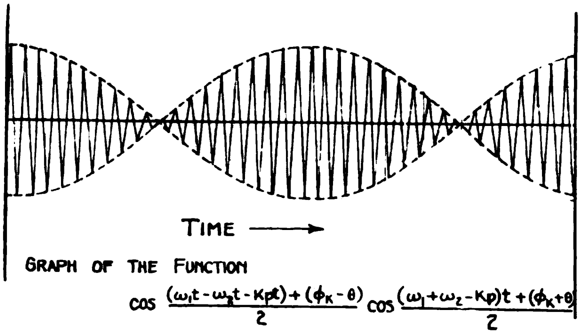

FIGURE 2

After rectification at the first detector tube the above frequencies are still essentially present and are impressed upon the amplifier proper. The frequencies $\frac{\omega_1-\omega_2\pm k\,p}{4\pi}$ are the heterodyne beat frequencies produced by interference of the local and signal voltages. The transformers of the amplifier are designed for frequencies of their order of magnitude and are not, therefore, affected by the radio frequencies $\frac{\omega_1+\omega_2\pm k\,p}{4\pi}$. No energy of these latter frequencies passes thru the amplifier. Neither does energy of the incoming signalling (radio) frequency ω_1 represented by the last term of (3), particularly if the transformers between stages of the amplifier are not broadly tuned. This is the normal way in which the amplifier works and is that described by Major Armstrong.

It is only the beat or difference frequencies

$$\frac{\omega_1-\omega_2-k\,p}{4\,\pi} \quad \text{and} \quad \frac{\omega_1-\omega_2+k\,p}{4\,\pi}$$

that have to be considered in designing the transformers and circuits. All of these frequencies lie in the neighborhood of the value

$$\frac{\omega_1-\omega_2}{4\,\pi}$$

which is the fundamental or basic beat frequency produced by the signal and local oscillations. They are greater and less than this value by the amounts

$$\pm\frac{p}{4\,\pi},\quad \pm\frac{2\,p}{4\,\pi},\quad \pm\frac{3\,p}{4\,\pi},\quad \cdots \quad \pm\frac{n\,p}{4\,\pi}$$

The transformers are fundamentally designed for the basic or mean frequency $(\omega_1-\omega_2)/4\,\pi$. This can be adjusted by regulating the local oscillation *but its proper value is by no means immaterial.* It is limited in the lower ranges by the fact that it must be above audibility, and thus about 20,000 cycles is as low as is permissible. The limitations in the other direction are those usually encountered in amplification of extremely high frequencies and a value of 5×10^5 cycles is about as high as can be used effectively.

The transformers should be as sharply tuned as possible to permit the building up of high voltages and avoid losses in resistance. A second requirement is that there shall be no distortion in the tonal quality of the received signal as it passes thru the transformers. This means that essentially all of the harmonics contained in the envelope curve of the arriving modulated oscillations must appear in the telephone current of the last detector. Thus, it is necessary to transmit equally thru the coupling transformers of the amplifier all of the frequencies.

$$\frac{\omega_1-\omega_2+k\,p}{4\,\pi} \quad \text{and} \quad \frac{\omega_1-\omega_2-k\,p}{4\,\pi}$$

and while designing the transformers for the basic frequency $(\omega_1-\omega_2)/4\,\pi$ the tuning must be broad enough so that the response is practically uniform over all the frequencies up to $n\,p/4\pi$ on either side of this basic value. A spark signal may contain appreciable harmonics up to the 10th or 20th which in a 500 cycle transmission of the usual type would mean that the amplifier transformers at the receiver would have to pass side frequencies up to 10,000 or 20,000 cycles above and below the basic frequency on which the design is based.

Laboratory experience has shown that it is difficult to build high frequency transformers tuned flatly enough to pass frequencies more than about 40 per cent above and below their best frequency. Even this value is accompanied by a marked loss of over-all efficiency because of the resistance effect, that must be introduced to broaden the tuning. It is obviously impracticable, therefore, to use transformers designed for a heterodyne frequency of 20,000 or 30,000 cycles, because a great many of the harmonic side frequencies that have to be transmitted to preserve the quality would be lost, and in order to get even a few of them the flat tuning required and the resistance inserted to secure it would mean low efficiency. It is much better in this case to work at a beat frequency of 100,000 cycles. The 10th harmonic in the spark signal under consideration, that is, 10,000 cycles, is then only off tune by 10 per cent which allows fairly good efficiency to be realized in the transformers. A beat frequency of 200,000 cycles would be even better.

There is another circumstance which favors the use of high beat frequencies, at least for the reception of short wave lengths, and that is that small changes in either the signal or the local oscillator frequencies such as might be caused by movements of the operator's hand or body in the neighborhood of one of the circuits, cause a much smaller percentage change in the beat frequency when this is high than when it is low, and the apparatus thereby becomes more nearly immune to such variations. At longer wave lengths, however, conditions are altered somewhat and there is an upper limit to the usable beat frequency.

The beat frequency can be produced with the local frequency (ω_2) either less or greater than the incoming frequency (ω_1). It is usually best, with short waves, to make ω_2 less than ω_1, because it is then more easily controlled and freer from variations of the type just mentioned.

LONG WAVE RECEPTION

In the reception of long wave lengths a condition arises in which the incoming signal frequency is of the same order of magnitude as the heterodyne frequency for which the transformers are designed. Such is the case, for instance, when receiving a wave length of 3,000 meters with an amplifier tuned to the beat frequency of 100,000 cycles. When this condition exists, the incoming frequency, $\omega_1/2\pi$, represented by the last term of (3), passes thru the amplifier together with all the heterodyne frequencies

$$\frac{\omega_1-\omega_2-kp}{4\pi} \quad \text{and} \quad \frac{\omega_1-\omega_2+kp}{4\pi}$$

and interfering with all of them in their different amplitudes and phases produces a conglomeration of resultants which will be heard in the telephones, after rectification at the last detector, as a badly distorted, mushy signal like that usually heard when receiving spark signals on an ordinary oscillating receiver. This will always happen if the incoming signal frequency passes thru the amplifier. In order to avoid the effect, therefore, it is necessary to design the amplifier for heterodyne frequencies that lie wholly outside the range of wave lengths to be received. It is easy to accomplish this, as will readily be seen, when short wave lengths are involved but when waves of one or several thousand meters are to be handled the proper selection of the value of the heterodyne frequency requires careful consideration.

As an example, consider the case of a receiver to function on all wave lengths from 1,000 meters to 5,000 meters; that is, 300,000 cycles to 60,000 cycles. In order to avoid distortion of the kind just mentioned on certain wave lengths this whole band of frequencies is at once eliminated from use as heterodyne frequencies in the amplifier, and the range ought to be extended at least 10,000 cycles beyond this at both ends because the spark signal may contain appreciable harmonics up to this value and certain of the side frequencies of the incoming oscillation might therefore get directly through the amplifier and produce distortion. In the case under consideration, therefore, the amplifier ought to be designed for a frequency either less than 50,000 cycles or greater than 310,000 cycles.

The disadvantages in using low heterodyne frequencies (on the 50,000 cycle end in this case) have been pointed out above in discussing the reception of short waves. Broad transformer tuning with comparatively low efficiency is required to avoid the other kind of distortion due to elimination or at least the reduction of the higher harmonics. But in addition to this there must be considered the fact that static is always more pronounced at long wave lengths and an amplifier designed for low frequencies might therefore be expected to be more affected by these disturbances than one using higher frequencies.

For these reasons it appears very desirable to design the amplifier transformers for a beat frequency of the order of 350,000 or 400,000 cycles, that is, about 750 meters, in the case under consideration.

If spark or telephone signals were to be received on extremely long wave lengths such, for instance, as 15,000 meters (20,000 cycles) there is another consideration that would come in to limit the upper value of heterodyne frequency that could be used. This may best be explained by reference to the formula (3) above. High heterodyne frequencies of the order of 500,000 cycles cannot be used in this case because the sum of the signal and local frequencies $(\omega_1+\omega_2\pm k\,p)/4\pi$ (carrier frequencies) would come thru almost as well as the difference or desired beat frequencies, namely, $(\omega_1-\omega_2\pm k\,p)/4\pi$ (modulating frequencies) and very bad distortion would result. To take the figures given, f_1, would be 20,000 cycles and f_2 520,000 cycles. Their sum would be 540,000 and their difference 500,000, a variation of less than 10 per cent and both therefore conceivably within the working range of an amplifier transformer.

The type of distortion discussed above which is caused by the passage of the incoming frequency directly thru the amplifier and which results in a mushy, harsh signal can be confined to a rather narrow range of wave lengths by making the tuning of the amplifier transformers sharp. But this cannot be carried to extremes or, as has already been explained, it will then not be possible to pass the side frequencies. These will, in telephone transmissions, probably not exceed 2,000 cycles either side of the basic frequency but in spark signals may run to 10,000 cycles or so in extreme cases.

SHARPNESS OF TRANSFORMER TUNING

In order to get an idea of the sharpness of tuning desirable in the transformers under different conditions the curves of Figure 3 are given showing the variation of secondary transformer potential as function of the ratio f_2/f_1 that is the ratio of the frequency to which the transformer secondary is tuned to the varying impressed frequency. Curve "a" is for a broadly tuned transformer of decrement 0.8; curve "b" represents sharper tuning with a decrement of 0.2. It will be seen that in the first case a frequency change of 10 per cent from the best value will cause a reduction in signal of about 5 per cent. In the second case, a difference in frequency from the best value of only 2 per cent causes the same change in signal.

If the 5 per cent reduction in potential for the side frequencies is assumed to be as much as is allowable in order to avoid distortion, and if it is further assumed that as sharp tuning as is represented by the curve "b" with 0.2 decrement is to be usable and the harmonics or side frequencies to be passed are to run to 5,000 cycles then the basic heterodyne frequency for which the transformers must be set will have to be at least 250,000 cycles; and if 10,000 cycles either side of the basic frequency are to be passed the latter cannot be less than 500,000 cycles, which is about the upper practical limit. It turns out, therefore, that curve "b" corresponding to a decrement of 0.2 represents about as sharp tuning as can be used, and even then it is necessary to use the higher range of available heterodyne frequencies. It is to be noted that this tuning is by no means sharp as judged by the standards usually set for radio circuits.

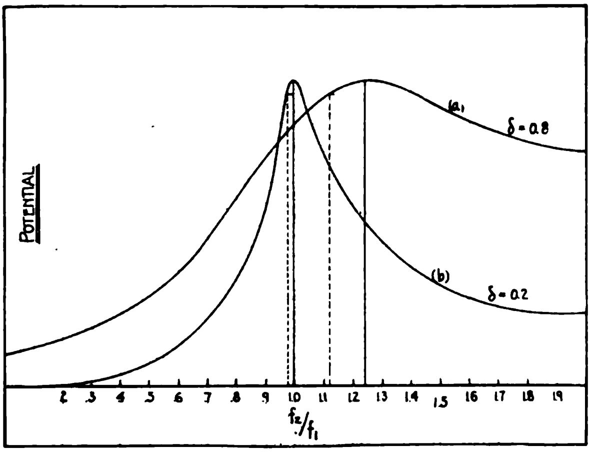

FIGURE 3

With such tuning, frequencies 15 per cent greater and 30 per cent less than that to which the transformer is tuned are only reduced in amplitude by one half, and considerable energy within these frequencies would get directly thru the amplifier and produce the distortion just mentioned with harsh signal. In figures, it may be expected, if the amplifier were tuned to 3,000 meters, that mushy signals would be obtained for all waves between 3,900 meters and 2,550 meters.

If low heterodyne frequencies are to be employed then the tuning must be broader and the resonance curve "a" applies. Here, the allowable reduction of 5 per cent in response occurs for a change of about 10 per cent in frequency from the optimum value which means that the latter must be set for at least 50,000 cycles if a side frequency of 5,000 cycles is to get thru sufficiently to prevent distortion. With such broad tuning, however, even frequencies of half the value for which the transformers are designed get thru directly with very little loss and distortion with the mushy, harsh type of signal may be expected over a wide range of wave lengths.

For purposes of design of the transformers it is possible from the above considerations to decide on the most suitable heterodyne frequency, the sharpness of tuning and the approximate decrement and to determine roughly the constants of the transformer from the relations

$$\delta = \frac{r_2}{2fL_2}$$

$$f = \frac{1}{2\pi\sqrt{L_2C_2}}$$

Still another point is involved here. In a pair of tuned coupled circuits such as must be used in the amplifier, the secondary and primary voltages are proportional inversely to the square root of the tuning capacities in the two circuits. That is

$$V_2 = \sigma V_1 \sqrt{\frac{C_1}{C_2}}$$

To get large secondary potentials, therefore, it is best to use small capacity and large inductance. Then, in order to keep the tuning or decrement to the desired value, the resistance must be increased, and these statements would hold without any qualification were the output of the vacuum tubes not definitely affected by the transformer load in their plate circuits.

When tuned, the secondary of a transformer introduces an effective resistance into the primary equal to

$$\frac{M^2\omega^2}{r_2}$$

so that changing the resistance of the secondary to secure the decrement required to pass the side frequencies affects the load on the tube. What is desired is to get as high a potential V_1 across the transformer primary as possible. This requires the load impedance to be high as compared with the internal tube impedance. Increasing r_2 therefore militates against this and the best results can only be secured by careful adjustment of all of the factors, coupling, resistance, and inductance to the frequency involved.

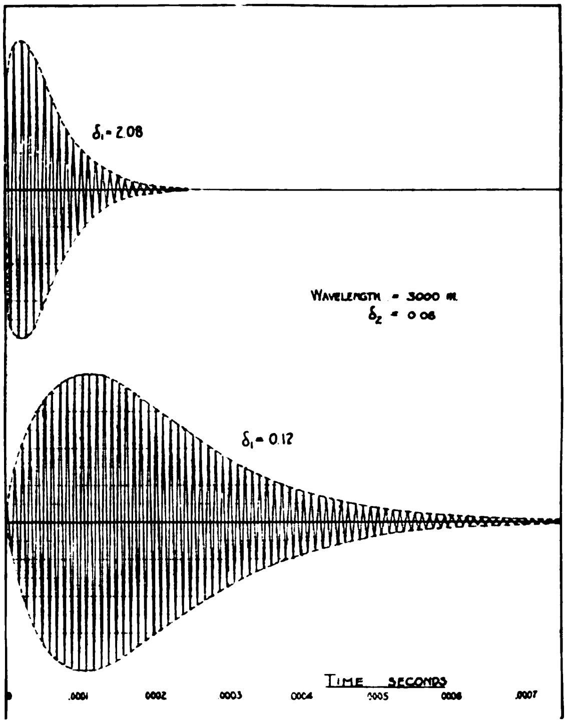

FIGURE 4

EFFECT OF TRANSMITTER DECREMENT AND ATMOSPHERICS

It appears that this type of amplifier functions most effectively on incoming waves of low decrement and that atmospheric disturbances which are always highly damped or else actually dead beat may be eliminated to a very considerable degree.

Curve "b" of Figure 4 shows a train of oscillations in a receiving circuit such as would be produced by a spark transmitter operating at 3,000 meters wave length and decrement 0.12. The decrement of the receiver for this curve was taken as 0.08. Curve "a" is similar but drawn for an excitation of high decrement, 2.08, approximating a static disturbance of the same frequency as that to which the receiver is tuned, that is, 3,000 meters. These curves can both be represented by equations of the form of equation (1) in which the Fourier's series gives the equation of the envelope curve of the oscillations.

For the curve "b," that is, the case of smaller damping, the different amplitudes of the harmonics and of the constant term in the representative series are as follows:

$V = 7.86$
$V_1 = 12.23$
$V_2 = 5.92$
$V_3 = 3.72$
$V_4 = 2.09$
$V_5 = 1.56$
. . . . .
$V_{10} = 0.40$

For curve "a" with high decrement the constants are:

$V = 23.6$
$V_1 = 38.4$
$V_2 = 24.0$
$V_3 = 19.2$
$V_4 = 14.3$
$V_5 = 12.2$
$V_{10} = 6.3$
. . . . .
$V_{20} = 3.36$

The amplitudes of the fundamental and various harmonics in the two cases are plotted in Figure 5 assuming the fundamental to be 1,000 cycles as in the usual spark transmission. It is seen that the amplitudes in the highly damped signal fall off much less rapidly than those of the more lightly damped signal. This means that in the former case a great deal of the total energy is contained in the harmonics, and if these are not passed thru the amplifier there will not only be distortion but loss in volume of signal as well. The use of a feebly damped spark transmission with an amplifier tuned just sharply enough to pass the principal harmonics or side frequencies produced therefore gives a system which largely eliminates static disturbances.

In this respect the present arrangement is more effective than the ordinary radio frequency amplifier. In the latter the presence of strong signal oscillations at the detector, after having passed the amplifier, amplifies the static in the same way that a locally produced frequency would, so that when the receiver is tuned to the incoming signal very loud sounds are caused by the static. These diminish rapidly, however, as the receiver is detuned, because the signal energy then falls off and the ratio of this, the equivalent local oscillation amplitude, to the static amplitude being thus reduced there results a much greater than proportionate decrease in the endodyne amplification effect on the static, as has already been shown by Major Armstrong in another paper.[1] But in the new amplifier only the fundamental and the first few harmonics of the static impulse are amplified by these interactions and thus much of the energy of such disturbances is lost.

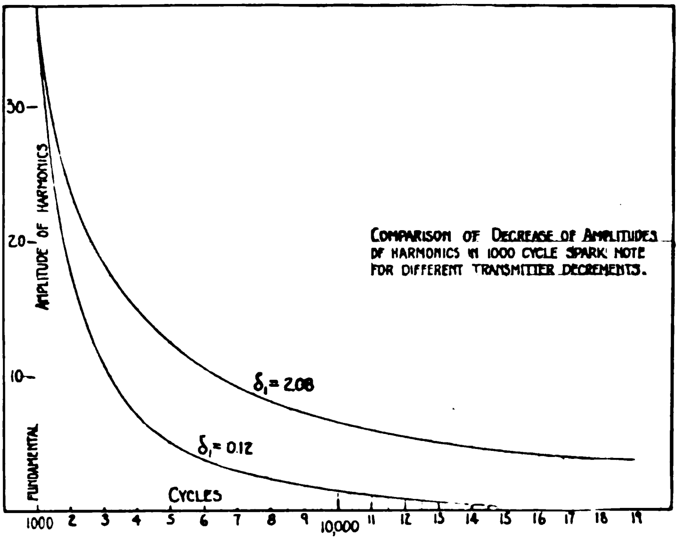

FIGURE 5

SUMMARY AND CONCLUSIONS

The above discussion has referred particularly to signals produced by spark transmitters, but the same general considerations are involved in telephone transmissions, except that in the latter the harmonic side frequencies to be considered will not generally exceed 2,000 cycles. The only point concerned in the case of sustained wave reception is that involving the passage of the incoming frequency directly thru the amplifier and this should be avoided with sustained waves for the same reasons that have been given to cover spark transmission.

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[1] E. H. Armstrong, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, April, 1917.

Several practical considerations have been omitted from the discussion. Of these, one of the most important is the difficulty that is encountered in placing the circuits of a radio frequency amplifier with their transformers in a box in such a way that sharp tuning may be obtained and yet not have the whole or part of the system go over into oscillation. This involves careful adjustment of the various couplings and the resistances of the circuits and the proportions and arrangements are usually different for every wave length. It is suggested that an improvement might be made in this type of amplifier over the circuits that have been drawn by Major Armstrong, in which he uses air core tuned transformers in all of the stages of the amplifier, by the use of a tuned air core transformer behind the first detector tube feeding the first stage of the amplifier and with the stages following this coupled by means of carefully designed iron core transformers. The latter keep down stray field, and it has been found possible to build such transformers so as to get practically the maximum attainable amplification from the tube. By this arrangement the sharpness of tuning required in the amplifier is furnished by proper design of the first air core transformer, and the trouble experienced from coupling back, when several stages all tuned to the same frequency are employed, is reduced by the use of the iron core transformers which follow.

Two kinds of distortion are to be avoided. The first is caused by the passage of the incoming frequency directly thru the amplifier. The second is due to the more or less complete elimination of the harmonic side frequencies in passing thru the amplifier due to excessively sharp tuning. The type of amplifier in question is best suited to use on very short wave lengths, at least below 300 meters. At long wave lengths it is difficult to avoid distortion of the first of the two kinds mentioned, which, in the case of spark signals, results in a mushy, harsh note. Above 600 meters this type of distortion may be expected to occur over a band of wave lengths from 15 per cent to 30 per cent above and below that for which the amplifier is designed.

As regards an estimate of the allowable sharpness of tuning in different cases it would appear that this lies approximately between the limits set by decrements corresponding to 0.2, as about the sharpest tuning allowable, to about 0.8 for the broadest tuning. The latter would not be allowable except perhaps for the reception of very short waves. These figures apply only to the case where several tuned transformers are used in cascade in the amplifier. If the arrangement using one air core transformer and the balance iron core broadly tuned instruments as just described be used, the tuning of the first air core transformer might be made considerably sharper than this, of the order usually found in ordinary receiving tuners.

In general, the basic frequency to be used in the design of the amplifier may be higher for long wave lengths than for short up to a certain point, the practical limit being in the neighborhood of 400,000 or 500,000 cycles for the reception of 6,000 meter spark signals. For very long waves the beat frequency cannot be made so high.

The analysis indicates that the amplifier can be made to be freer from interference from highly damped spark stations and static disturbances than the usual types.

There is one other point that has not been mentioned tho I know it has already occurred to Major Armstrong himself. That is the question of the extent of the loss, if any, in effecting the change of incoming signal frequency to the value for which the amplifier is built. An experiment made[2] at Camp Alfred Vail in which the signal received on a simple non-regenerative tube was compared with that obtained by Major Armstrong's arrangement using a separate heterodyne, a rectifying tube for the super-audio note, and a detector tube, indicated that about equal signals were obtained by each method. Apparently, the heterodyne amplification in the second case just about makes up for the loss which accompanies the change in frequency.

Radio Laboratories,
Camp Alfred Vail, New Jersey,
December 4, 1919.

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[2] By Mr. M. C. Batsel, Assistant Radio Engineer, Signal Corps, United States Army.

X

THE RELATION BETWEEN ATMOSPHERIC DISTURBANCES AND WAVE LENGTH IN RADIO RECEPTION*

By

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The fact that the atmospheric disturbances, commonly called "static" or "strays" by American operators, increase with the wave length to which the receiving system is tuned has been known qualitatively for a number of years. The object of the present experiments is to gain some degree of quantitative information on the subject.

Neglecting the lightning clicks and hissing disturbances which for the most part produce little interference with communication, we have in general to deal with the rumbling or grinding static which probably originates somewhere in the upper atmosphere, and which may perhaps be compared in its method of propagation to radio signals sent out from an airplane. Regardless of the orientation of the original oscillating body, the wave front spreads out in a more or less spherical form. When the wave strikes the earth the lines of force become grounded and travel off over the surface as tho transmitted from an antenna situated at some point roughly below the center of disturbance. Observations which will be described in another place, show that the wave front at 50 ft. (15 m.) from the ground is approximately vertical like that from a distant sending station. Of course there will be some disturbance centers nearly overhead, but these generally form only an insignificant portion of the whole.

It has frequently been thought that static is entirely aperiodic, and that it produces a pure shock effect on the antenna. This seems somewhat doubtful, since none of the aperiodic types of artificial static produced in the laboratory, even of the most violent kind, have ever been anywhere nearly so difficult to eliminate as the natural disturbances. It seems more probable that it consists of a great number of distinct disturbances coming from different sources and of widely varying wave lengths, thus producing a practically continuous disturbance spectrum, so that to whatever wave length the receiving apparatus is tuned, a corresponding static wave length is found.

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*Received by the Editor, January 15, 1920. Presented before The Institute of Radio Engineers, New York, May 5, 1920.

According to observations made independently at a number of points on the North Atlantic Coast, the heavy afternoon and night summer static appears to come generally from the southwest, while the lighter static of the forenoon and that observed during the cooler portions of the year seems to be more evenly distributed in regard to points of the compass. It is also to be noted that this southwest static is usually more continuous than the other.

The following experiments have been carried on at the Naval Radio Laboratory at the Bureau of Standards, and the receiving apparatus used is that described in the Nauen-Eilvese experiments[1] and in an article on the measurement of radiotelegraphic signals.[2] The method of observation was as follows:

The Laboratory antenna and secondary receiving circuit containing an oscillating audion were set on the required wave lengths, the adjustments being made as described in the articles cited. The strength of the disturbances was measured by the shunted telephone method, and since the individual disturbances vary in intensity from second to second, it was necessary to adopt some arbitrary method of procedure in determining their audibility. After experimenting with different plans, it was decided to call the audibility of the disturbance, the setting of the audibility meter at which an average of three pulses of disturbance could be heard in the telephones in ten seconds. The observations were taken at about 10 a.m. and 3 p.m., the time consumed in each series for the range 3,000—18,000 meters amounting to less than 15 minutes. On account of the lack of a definite pitch in the atmospheric disturbances as heard in the telephones, the accuracy of observation is, of course, much less than in the measurement of received signals. For this reason, and on account of the irregularity of the phenomenon, the results are given in the form of curves rather than numerical tables. The work was begun in August, 1917, and since May, 1918, has been made a part of the daily routine of the laboratory. Of course it is impossible in an article of this kind to give more than a very small portion of the data accumulated. Therefore, it has seemed best to pick out sample periods which are typical of the general conditions observed.

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[1] "Journal of the Franklin Institute," page 605, 1916.

[2] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, page 239, 1917.

Figure 1 gives a series of observations extending from November 1 to November 14, 1917 taken at 3 p.m. The observations were taken every 1,000 meters between the wave lengths of 3,000 and 10,000 meters, and every 2,000 meters from 14,000 to 28,000 meters. These curves are typical of the variation in the disturbances with wave length during most of the year.

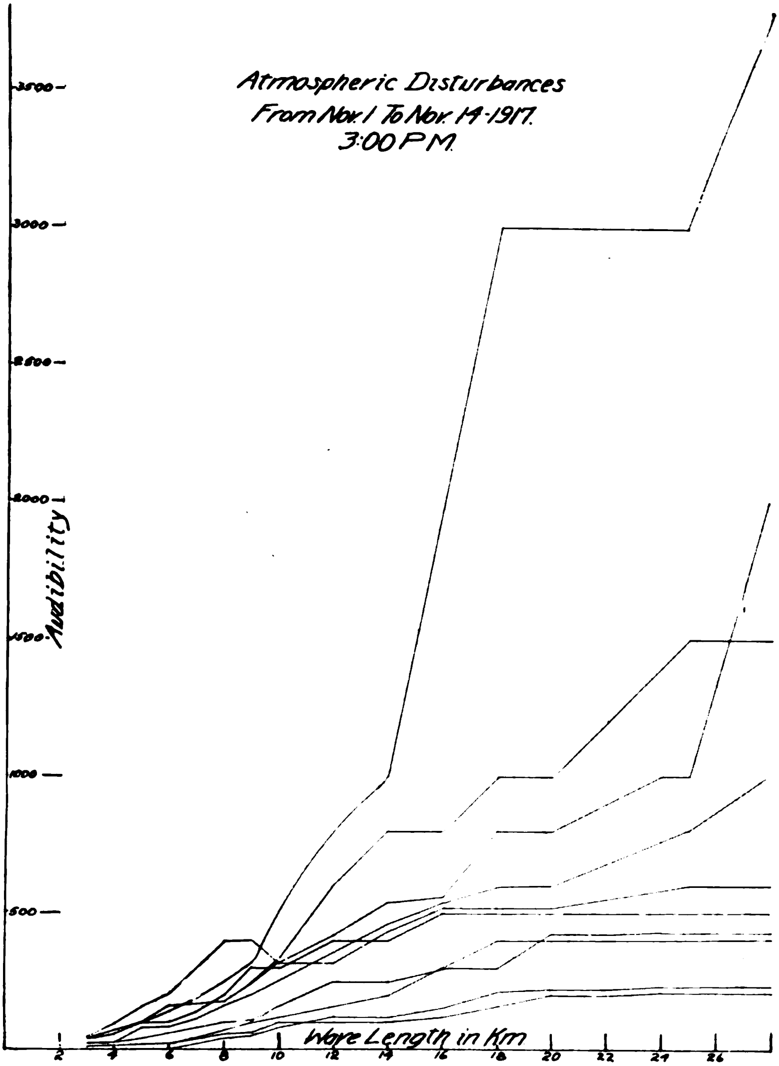

FIGURE 1

The forenoon observations are similar in form, tho somewhat lower in average audibility than during the afternoon, especially in summer. It is seen that, in general, there is a rapid, tho irregular rise in intensity with wave length and that occasionally, tho rarely, a maximum is found with a subsequent decline in intensity. In some cases, the rise extends only to a definite wave length, beyond which the intensity remains constant over a considerable range.

Figure 2 shows observations taken at 10 a.m. between December 1 and December 18, 1917, and covers the wave lengths between 3,000 and 16,000 meters, which is the range ordinarily employed in present-day long distance transmission. Figure 3, covering the period from August 16 to September 5, 1917, shows a time of unusually heavy afternoon summer disturbances. Disturbances of this character have hardly occurred at all during the summer of 1918 and 1919. The figure shows a much more rapid rise in intensity with wave length than is shown in Figures 1 and

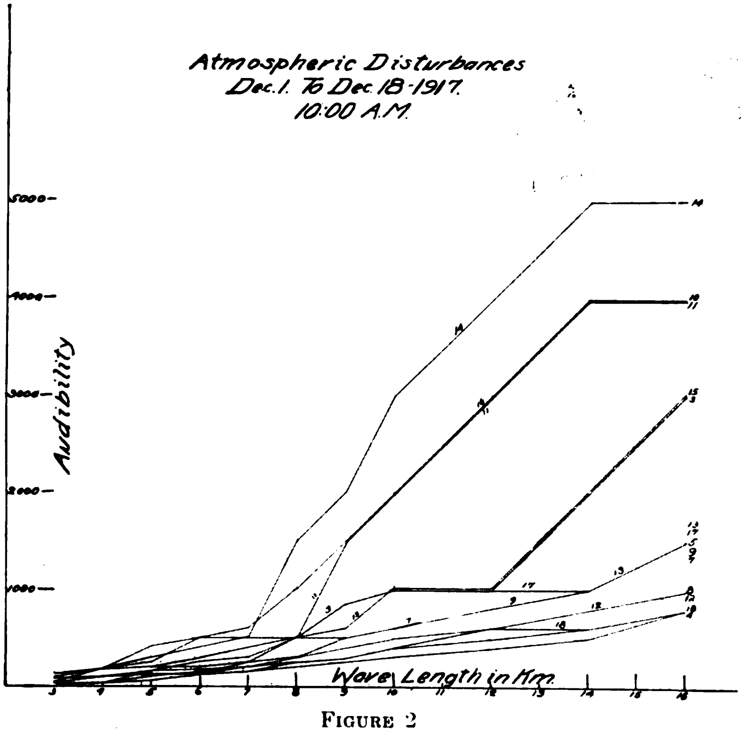

FIGURE 2

2, the intensity increasing often two or three times in an increase in wave length of 1,000 meters. The curves practically all run out nearly flat within the limits of the observations, after their initial rise.

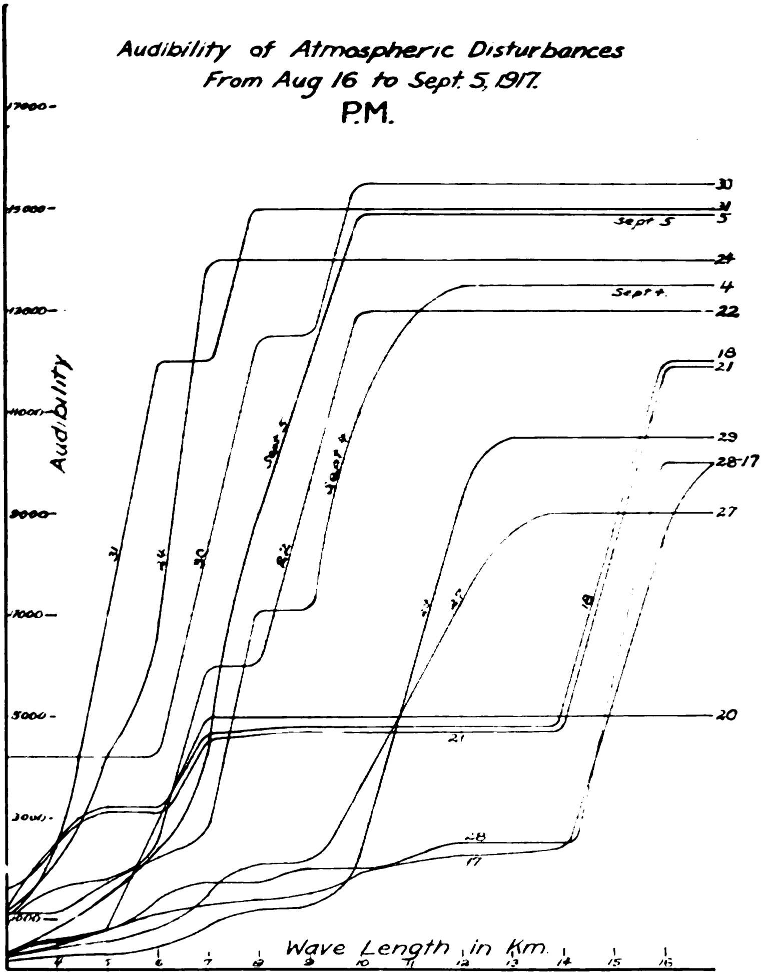

FIGURE 3

Figure 4 shows the forenoon observations covering the same period as Figure 3. The curves are quite distinct in character from the corresponding afternoon curves.

Figure 5 represents the static during the last half of August

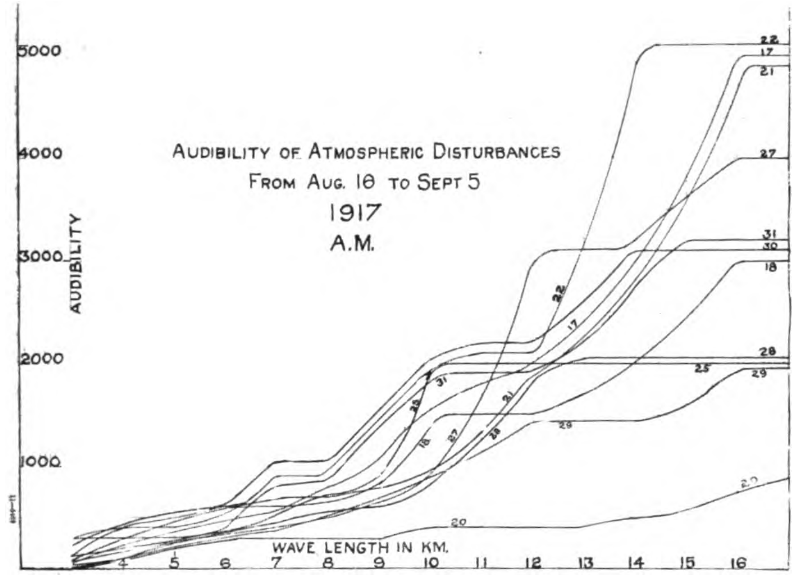

FIGURE 4

in 1919. The curves are evidently entirely different from those of the same period in 1917 (Figure 3) and correspond more nearly to the curves of Figures 1 and 2.

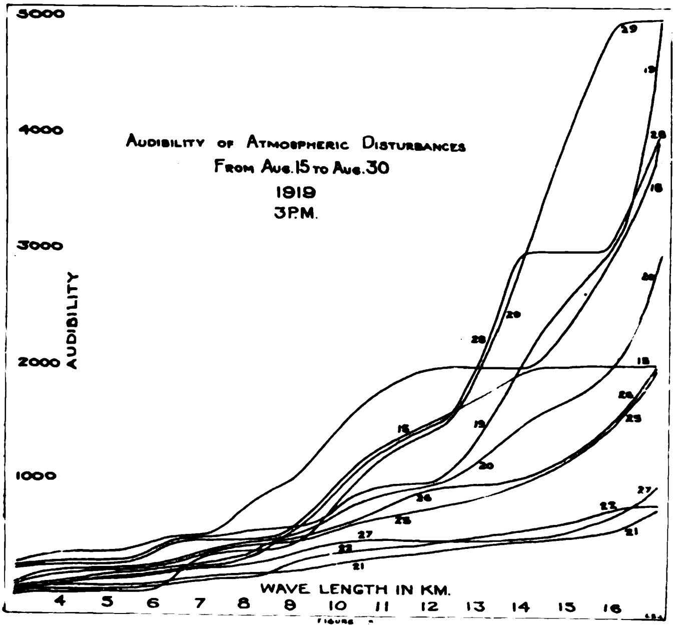

FIGURE 5

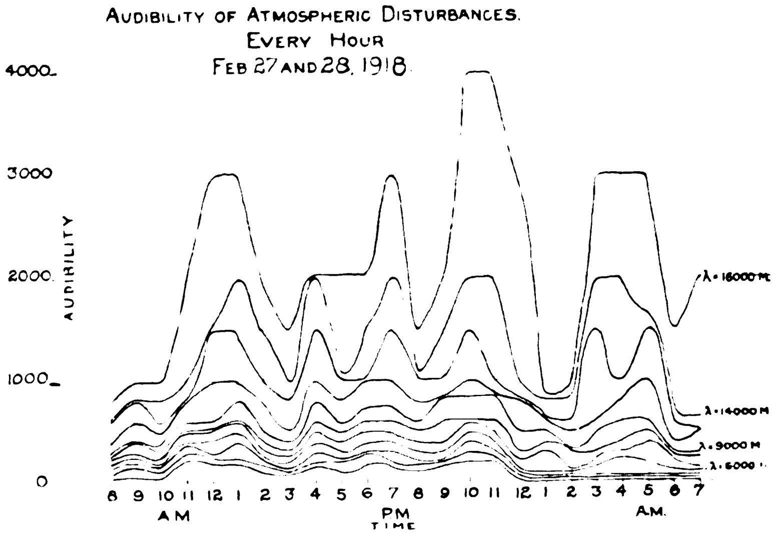

FIGURE 6

Sets of observations at the various wave lengths have been taken every hour for a period of 24 hours once a month during the last two years. Figure 6 shows the curves of a typical 24-hour test. It is seen that in general the maxima and minima of the different wave lengths correspond closely, altho there are many irregularities which may or may not have significance. There are always well marked minima at about half-past-one in the morning and at about daylight, and in addition there are always two or three other prominent minima present which shift position somewhat from day to day. There is little difference between winter and summer in the general appearance of the curves of daily variation.

1. Static increases rapidly with the wave length being on an average about twenty times as strong at 17,000 meters as at 3,000 meters. This increase is generally roughly proportional to the wave length.

2. There is at times especially during periods of unusually heavy afternoon summer static, a sudden increase at moderate wave lengths after which the intensity seems to remain nearly constant, so that the curve resembles a strongly damped resonance curve.

3. The strength of summer static varies greatly from year to year, the average during August, 1917 being about three times

as strong as that observed in the same month in 1918 and 1919. August, 1917 was also a month of exceptionally strong European signals.

U. S. Naval Radio Research Laboratory,
September, 1919.

SUMMARY: The apparent wave length of atmospheric disturbances at different times of the day and year is studied, and the results obtained are shown graphically and by description.

DISCUSSION

Greenleaf W. Pickard: Dr. Austin's paper is unquestionably a most valuable contribution to our knowledge of static disturbances. Altho in the past it has been generally recognized that static increased with the wave length setting of receivers, this paper has brought out two striking facts: first, that up to a certain wave length the increase in static intensity is nearly directly proportional to the wave length, and second, that after this critical wave length is passed, there is no further increase or even change in intensity.

But I do not find myself in agreement with the static theory briefly expressed in this paper. Instead of regarding static disturbances as a summation effect of many *oscillatory* discharges of different frequencies, I believe that the observed facts are better and more simply explained on the basis of *aperiodic* discharges. It is, of course, elementary that any imaginable wave form may be resolved by Fourier's theorem into a sine cosine series, and therefore might be built from a large number of suitably chosen undamped or feebly damped wave-trains. Actually, the various complex pulses known to us seldom or never have this genesis, and their resolution into a more or less infinite series of oscillation trains is merely a convenient mathematical analysis.

One of the simplest and best known aperiodic pulses is that caused by the discharge of a condenser through a circuit having a fixed ohmic resistance equal to or greater than $2\sqrt{L/C}$. In Figure 1 is shown a series of "resonance" curves for such pulses, when received on a feebly damped circuit corresponding to the ordinary receiving circuit. The full-line curve represents the usual i^2 readings in the wave-meter circuit, when acted upon by a condenser discharge in a neighboring circuit having twice the critical resistance. The broken line curve is that due to a just critically damped or non-oscillatory circuit, while the dot-and-dash and dotted line curves are due, respectively, to discharges in circuits having 0.5 and 0.25 the critical resistance, and hence oscillatory.

Dr. Austin employed an oscillating audion for his static measurements, and as he has pointed out[1] this detector responds in proportion to the first power of the received current. In Figure 2 is shown a plot of the first two curves of Figure 1,

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[1] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 4, page 252, 1916

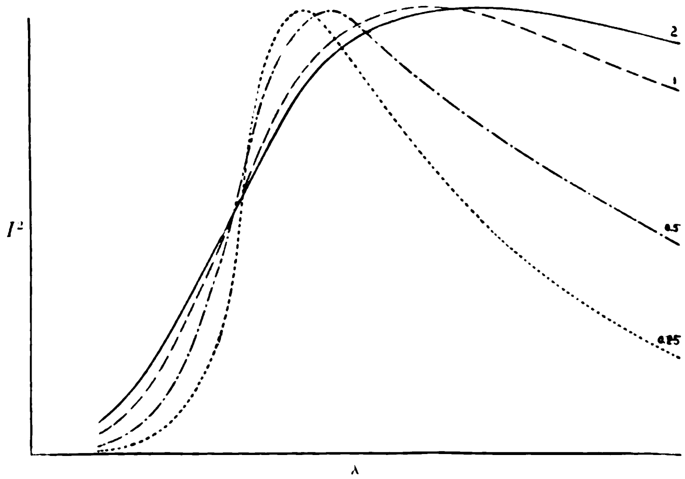

FIGURE 1

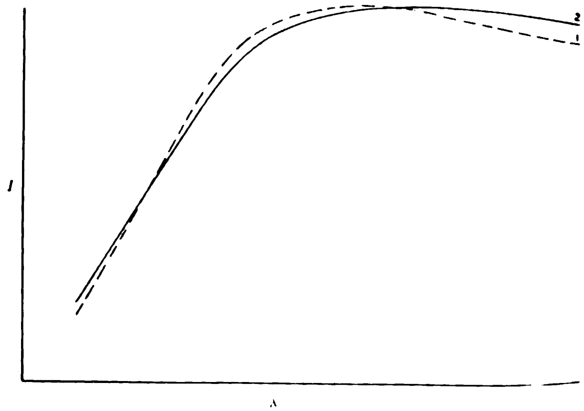

FIGURE 2

but with ordinates of current instead of current-squared. Their resemblance to the curves shown in the paper is striking.

It is altogether likely that if Dr. Austin had carried his measurements up to a wave length of 25,000 or 30,000 meters, he would have observed a decrease in the intensity of static. I have made a few comparative measurements of static intensity on these longer wave lengths, which show a clearly marked falling off in intensity above 25,000 meters.

I have found that the static measured by Dr. Austin on

August 27, 1917, may be well duplicated in the laboratory by a condenser discharge in a circuit tuned to about 16,000 meters, with sufficient ohmic resistance to give critical damping. This would indicate that the aperiodic "oscillator" responsible for the disturbance had a length of some eight or ten kilometers.

Frederick K. Vreeland: I have read with great interest Dr. Austin's paper, which furnishes an interesting confirmation of some of the conclusions regarding the nature of atmospheric strays derived by different means, and throws some illuminating side-lights on the subject.

Dr. Austin has said that the effect of strays on a receiving circuit tuned to variable frequency is analogous to that which would be produced by a continuous spectrum of waves of different frequencies. This is precisely the effect that is produced by an aperiodic transitory impulse, as has been well established by the analytical study of transients, and has been neatly illustrated, for certain special cases, by the experiments with artificial pulses described by Mr. Pickard.

Furthermore, the distribution of amplitudes among the wave lengths in this apparently continuous spectrum depends upon the decrement or rate of decay of the pulse. Thus, if we allow a given pulse to excite shock oscillations in a tuned circuit of small decrement, the energy of the oscillations increases with increasing wave length at a rate depending on the rate of decay of the pulse, and finally reaches a limiting value beyond which the change of energy is small.

Putting the matter rather crudely for the sake of simplicity, let us assume that the exciting pulse is relatively sluggish, that is, that its rate of decay is so slow that it persists over a period of several complete oscillations of the resonant circuit. It will be seen at a glance that the effect of the initial impulse in starting the first half wave of the oscillation will be partially neutralized by the smaller effect on the second half wave, the direction of which is reversed while the direction of the exciting pulse is unchanged. The oscillation will again be augmented in smaller degree during the period of the third half wave, and again diminished during the fourth, and so on until the exciting pulse has expended itself. It is thus evident that the effective value of a slowly decaying pulse is confined mainly to the initial impulse, the energy of the remainder of the pulse being ineffective.

If now, keeping the form of the exciting pulse unchanged, we increase the natural period of the oscillating circuit, it can be readily seen that the effect of the pulse in exciting shock oscillations will increase at an increasing rate with increasing wave length of the circuit, until a point is reached where the period of a half oscillation is sufficiently great to include practically the whole duration of the exciting pulse. The entire energy of the pulse is thus effective in exciting the shock oscillation, and the change in energy of this oscillation with a further increase in the wave length will be relatively small.

This is precisely what is shown in a general way by Dr. Austin's curves, showing the effects of atmospheric strays, and confirmed for special cases by Mr. Pickard's experiments with artificial pulses of known form. The curves show a rise at an increasing gradient up to a certain wave length, at which they suddenly flatten down and continue without further material increase. It thus appears that the results derived from theoretical study, considering the effect of a decaying aperiodic pulse, are borne out in a general way by the tests, within the limitations of the experiments. Dr. Austin's results are thus in accord with the conclusion, reached by other means, that atmospheric strays are largely of this character, as I have stated in former discussions.

A very interesting feature of Dr. Austin's curves, to my mind, is the manner in which the form of the curve varies under different conditions and at different times. It appears in a general way that the more intense strays produce a more rapidly rising curve, which reaches its flat portion at a smaller wave length. The height of this flat portion, however, is not fixed, but varies from time to time. One would naturally conclude from this that the most intense strays are as a rule the most abrupt, that is, their decrement is greatest, but that the relation between intensity and decrement varies from time to time. Thus, the curves for winter strays show a relatively gradual and continuous increase with increasing wave length, without reaching a maximum. The curves for the most violent summer strays, on the contrary, rise very rapidly and reach their critical value at a relatively short wave length, showing that these strays are very transitory, that is, they have a large decrement.

It would not be safe, however, to jump at any generalization regarding the relation between stray intensity and the form of the pulse. Anyone who has done serious work with strays knows better. On the contrary, Dr. Austin's curves, while indicating a rough general relation, also indicate certain notable exceptions. For example, some of the curves rise rapidly to the flat portion, continue horizontally over a considerable range of wave lengths, and then rise again abruptly at the longest wave lengths. In other curves this flat portion appears only as a relatively small jog in the curve. These discrepancies would seem to indicate that while the bulk of the strays observed are of short duration, there are some very powerful ones, the decrement of which is low, and which therefore affect the circuit chiefly at the longest wave lengths.

Here again we should guard against jumping at conclusions, for it is evident that an intense pulse may owe its intensity either to the intrinsic magnitude of the stray or to the proximity of its source. Thus, in some cases a very powerful stray may be of the same essential nature as other strays, which are usually weak, because their source is more distant.

Finally, we should bear clearly in mind the fact that Dr. Austin's observations do not relate to strays in general, but are limited to the most powerful strays occurring at any given time, in other words, those strays that are so exceptional that they occur only three times per second. It would be unsafe, therefore, to draw any conclusions regarding the great bulk of strays which produce the major part of the disturbance.

May we not venture to hope that Dr. Austin will continue and extend these very illuminating researches to include not only the exceptional strays, but all the strays which make up the complex effect? Such a statistical study, for which Dr. Austin has shown himself so admirably qualified, would doubtless throw much light on the subject, and would probably show curves of quite different form when the less intense and more frequent pulses are considered.

THE REDUCTION OF ATMOSPHERIC DISTURBANCES IN RADIO RECEPTION*

By

Louis W. Austin

(Head of the United States Naval Radio Research Laboratory at the Bureau of Standards, Washington, D. C.)

When the United States entered the war, it became highly desirable to establish radio communication with France sufficiently perfect to render the two countries independent of the cables, since these were at all times subject to danger of destruction by the enemy. For this reason great efforts were made by the Navy Department to improve apparatus and methods used in long distance radio work, and special efforts were directed toward the production of devices and circuits for the suppression of atmospheric disturbances, commonly known as static or strays, which it is well known form one of the chief obstacles to perfect radio reception. These disturbances are generally the strongest during the summer months in our latitude, and usually increase to a maximum in the late afternoon, that is, they are at their worst at a time of the year and time of day when the European signals are weakest at most of our receiving stations. Without attempting to discuss at length the origin of these disturbances, it may be mentioned that there are at least four types, all of which may arise from distinct causes. The most common type produces a rattling or grinding noise in the telephones. A second type, associated with snow or rain, gives a hissing noise. The third, due to lightning flashes, gives a sharp snap, while a fourth produces a noise somewhat like the first type but more crashing in character. This last seems in summer to be associated with thunder storm conditions, but it is also common, tho not usually as strong, in autumn and winter.

The early attempts to improve the signal static ratio[1] lay largely in the direction of improvements in the secondary receiving circuit such as limiting the response of the detector to strong disturbances, using tuned and sometimes balanced audio frequency circuits, circuits in which an oscillating and non-oscillating audion were balanced against each other and their audio frequencies united in the telephones thru a differential telephone transformer, and many other unsuccessful devices in which numerous modifications of the secondary circuit were tried.[2]

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*Received by the Editor, October 30, 1919. Presented before The Institute of Radio Engineers, New York, April 7, 1920.

[1] According to Commander A. H. Taylor, a readable signal is generally obtained if the audibility of the static is not greater than four times that of the signal; that is to say, if the signal-static ratio is better than 25 percent. From our experience this is generally true, but it is evident that this must depend on the continuity of the static. Sometimes a ratio of 50 percent is hardly

As far as our knowledge now goes, the most successful method of static reduction employing the ordinary antenna alone, makes use of an exceedingly stiff primary circuit combined with a very stiff tuned audio frequency telephone circuit, us ng also sometimes a tuned audio amplifier. A good form of antenna circuit is shown in Figure 1.

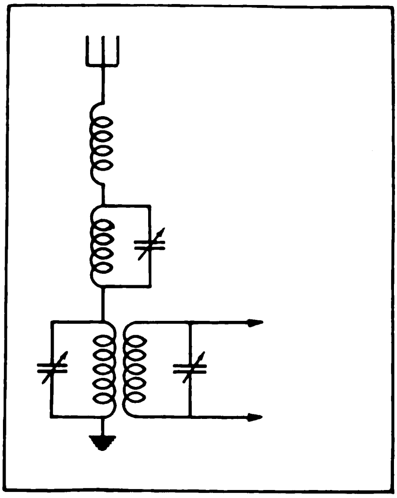

FIGURE 1

The closed loop or coil antennas and the underground and underwater antennas, which were considered very promising static reducers at one time, have not in their simple forms been

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readable while at other times 18 to 20 percent can be read. In these estimates it is assumed that the static audibility is the reading of the audibility meter at which the static can be heard three times in ten seconds.

[2] It must not be forgotten that the oscillating audion in comparison with the older types of detectors is itself the best static reducer known. (See "Quantitative Experiments with the Audion," "Washington Academy Journal," IV, page 84, 1916.)

found of much value at Washington in improving the ratio of signal to static. In oscillating audion reception of continuous waves, if the ratio signal over static is taken as unity for a good receiving antenna of the ordinary type, the ratio for a loop will be about two, while a good underground antenna in moist earth or fresh water will generally give a ratio of from two to three in the case of ordinary disturbances, but it should be noted that the buried antenna is entirely protected from true static induction, which, in the case of thunder clouds directly or nearly overhead, may produce severe disturbances in the telephones.

By the spring of 1918, four circuits had been developed, three in the Navy Department and one outside, which showed a substantial improvement in reception thru the atmospheric disturbances. In order to obtain information in regard to their relative merits, comparative reading tests were carried on during that summer on signals from some of the high power European stations. The receiving stations were:

The Marconi Experimental Station at Lakewood, New Jersey
(Weagant system)
The Marconi Station Under Naval Charge at Belmar, New Jersey
(Taylor system)
The Experimental Station of the Naval Radio Research Laboratory on the Anacostia River at Washington, D. C.
(Laboratory system)
The Naval Station at Otter Cliffs, Maine
(Otter Cliffs system)

The first three stations could be quite fairly compared since they all lie in a region where the conditions of reception are similar, altho conditions at Washington are slightly less favorable than at the other two. The comparison of Otter Cliffs with the other stations is of less value in respect to the excellence of the systems employed, on account of the differences in distance and climate in the two regions.

LAKEWOOD

The receiving station at Lakewood, New Jersey, employed a system developed by Mr. Weagant[3] (see Figure 2). The antenna consisted of two single-turn loops supported on telegraph poles extending for a distance of three miles (5 km.) each way from the receiving station. The loops lay in the direction of propagation of the incoming waves from the European stations, and had a height of about 18 feet (5.5 m.) between wires at their outer ends, which decreased to 3 feet (0.92 m.) at the station. They were tuned by means of variable capacities and inductances, a part of the latter being inserted in the line at a distance from the station. The loops ended in the station in the two primaries of a large Bellini-Tosi goniometer and acted in opposition on the goniometer secondary. This last formed a part of an intermediate circuit which was in turn coupled to the usual secondary receiving circuit. Tho the loops were connected in opposition, the difference in phase due to their length resulted in a marked strengthening of the signal. At the same time the static was greatly reduced. According to Mr. Weagant, this reduction in static was due to the fact that static comes from above and thus acts in an equal and opposite sense on the two loops. This explanation seems very improbable, since if it were true, any antenna consisting of a vertical wire would be free from static.

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[3] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 7, page 207, 1919.

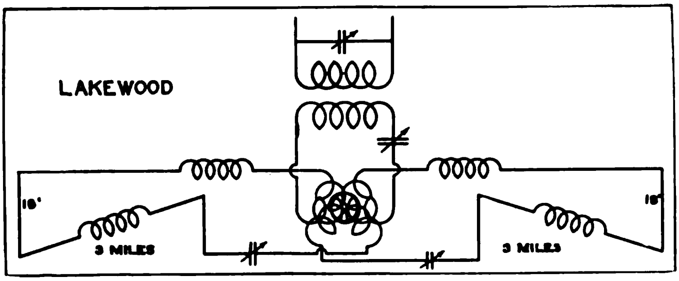

Figure 2

Belmar

At Belmar the resistance balance system of Commander A. H. Taylor[4] was employed. The most recent type of circuit is shown in Figure 3. For the Nauen reception, the loop antenna L had 16 turns and was 75 feet (22.9 m.) long and 45 feet (13.7 m.) high. W was a well-insulated water wire about 1,500 feet (458 m.) long lying just below the surface in salt water. The signal in the water wire was exceedingly weak compared with that in the loop. The variable resistance R' served to increase the natural difference in signal static ratio of the loop and water wire, while R was a resistance with sliding contact used to obtain a balance between the static of the loop and that of the water wire. By this arrangement the signal static ratio of the combined system was rendered much better than that of the loop or wire alone. On account of the resistances employed, the signals were generally very weak so that considerable amplification was necessary. Five similar systems of loops and water wires were used for receiving various stations.

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[4] Proceedings of The Institute of Radio Engineers, volume 7, page 559, 1919.

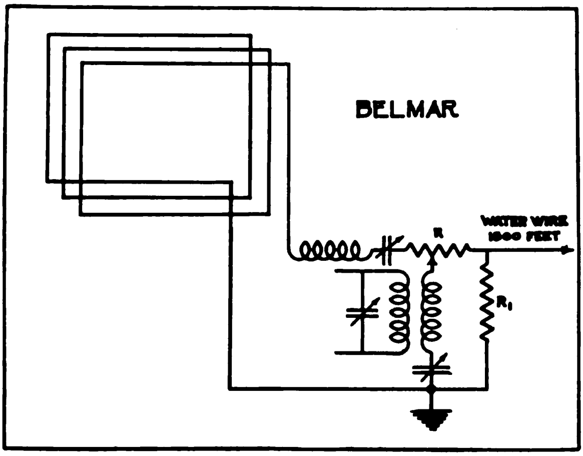

FIGURE 3

THE RADIO LABORATORY'S RIVER STATION

This station is situated on the Anacostia Flats a little below the Washington Navy Yard. The circuits are shown in Figures 4 to 8. The loop used during most of the summer of 1918 was 90 feet (28 m.) long and 30 feet (9.2 m.) high with 8 turns. This was later replaced by a higher and shorter loop in which the number of turns could be varied by switches. The well-insulated water wire 1,000 to 2,000 feet (305 to 610 m.) long lay in the brackish Anacostia River not far from the bank, while the surface wire lay along the top of the retaining wall. The condensers C_1, C_2, C_3, and C_4 (Figure 4) acted as coupling condensers controlling the energy flow from the loop and from the two wires. The antenna tuning was practically all done with the condenser C. In this circuit it was intended to take advantage of the difference in signal-static ratio of the water and surface wires discovered in the work at Piney Point in 1917, and also of the difference in this ratio on the loop and water wire. A considerable improvement in the action of the circuit was brought about by shunting a 30 millihenry inductance across the condensers C_1 and C_2 between the loop and water wire.[5] The theory of this circuit in regard to the reduction of static is not yet fully understood. While it may depend in part on the difference in static-signal ratio in the surface and water wires, the main effect is apparently due to the combination of the loop with a water or ground wire, as very good results are obtained with the surface wire removed (see Figure 5), and almost as good results with the water wire replaced by the surface wire. The circuit is extremely unidirectional, being much stronger for signals coming from the direction of the extended wire than from the opposite direction. (Note: The experiments indicate that a great improvement may be expected in all loop reception by attaching a wire lying on the ground to the loop, in the manner indicated. For waves less than one thousand meters in length, this wire would need to have a length of only one hundred or two hundred feet (30.5 to 61 m.).) This unidirectional character of the circuit is probably an important factor in the reduction of static in European reception, as experience has shown that in this part of the country at least

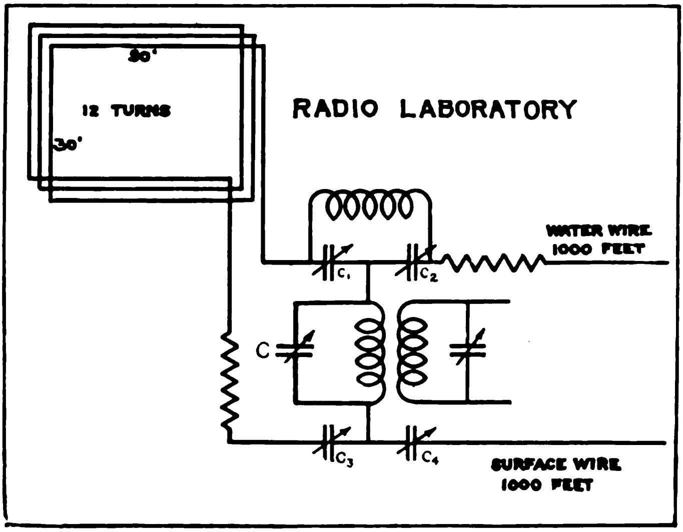

Figure 4

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[5] This was introduced about September 1, 1918, and accounts in part for the improved work after that date. (See Table 1).

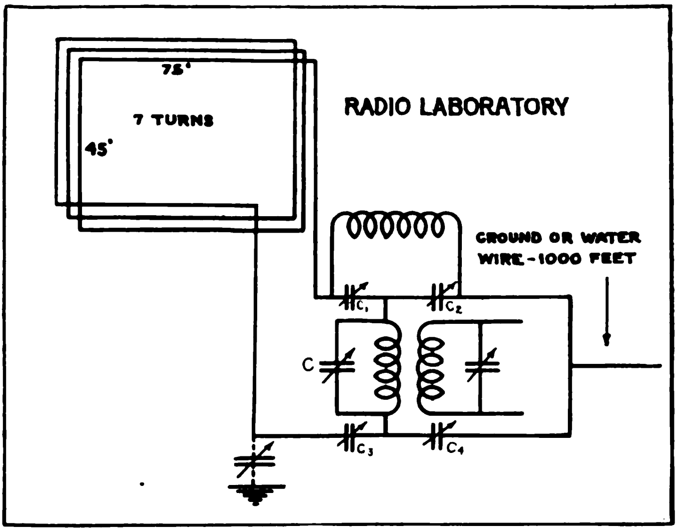

FIGURE 5

a large part of the first type of static (the most frequent kind) comes from the southwest, a direction almost exactly opposite to that of the European stations. It is also observed in confirmation of this idea, that using a water wire extending to the south-

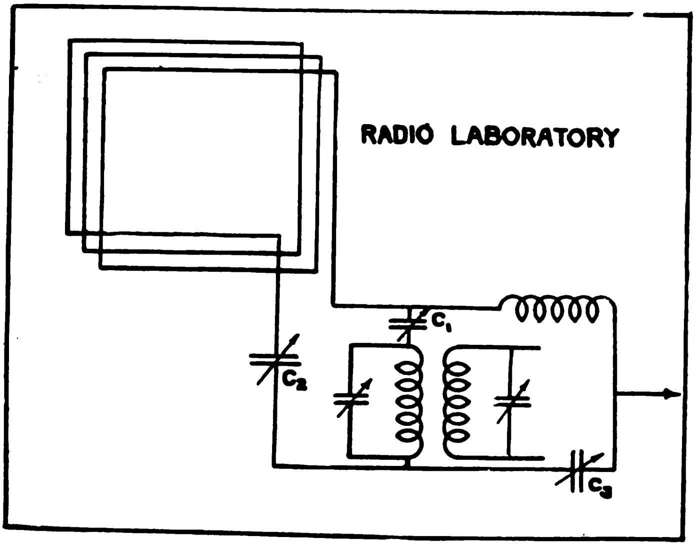

FIGURE 6

west for reception from that direction, the static reduction is less satisfactory than in the European reception.

Since the completion of the 1918 tests, a number of modifications and simplifications have been made in the laboratory circuits, Figures 6 to 8, which are for the most part due to Mr. Clausing, of this laboratory. The circuits appear to be quite as efficient as the original form. They all represent various applications of condenser control to the balancing of loops and ground or water wires.

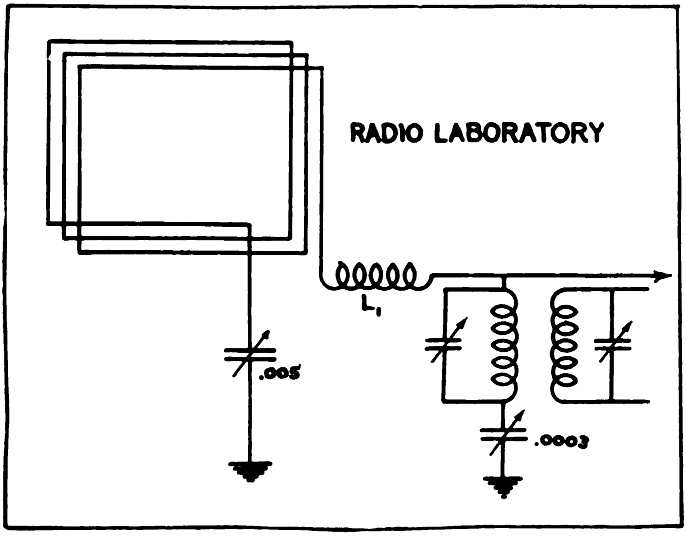

FIGURE 7

OTTER CLIFFS

The circuit shown in Figure 9 has been used at Otter Cliffs since the middle of the summer of 1918. It consisted essentially of an ordinary tuned loop of 3 turns, 125 feet (38 m.) long and 25 feet (7.6 m.) high with 20-inch (51-cm.) spacing, interwound with an open end untuned loop of 3 turns connected to ground thru an inductance of 30 millihenrys and a variable resistance of from 5,000 to 60,000 ohms. The closed loop was coupled both to the open loop and to the secondary circuit, and the reduction in static was accomplished by the adjustments of the two couplings and the variation in the grounding resistance. The interwinding of the loops produced a close condenser coupling between them in addition to a distributed inductive coupling. The circuits formed a combination which was evidently highly unidirectional, and probably there was also some differential action due to differences in decrement on the signal and static as in the loops and water wires at Belmar and Washington.

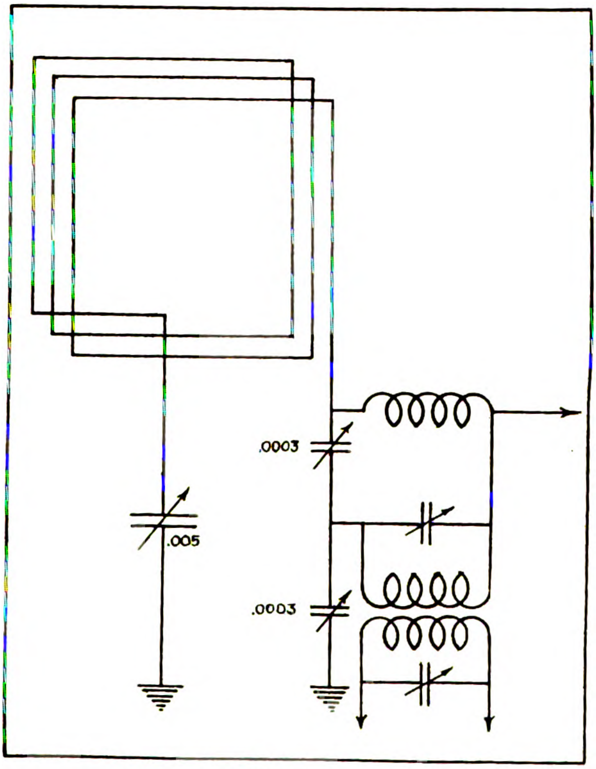

FIGURE 8

The situation of Otter Cliffs near Bar Harbor was much more favorable for European reception than that of the other stations described. To begin with, the distance from the sending stations was less by more than 500 miles (800 km.) and this alone, according to the Navy Transmission Formula, insures about double the strength of signal. In addition, the climatic conditions are such that the signals are less variable than in the more southern regions of the country and the atmospheric disturbances are probably in general less severe.

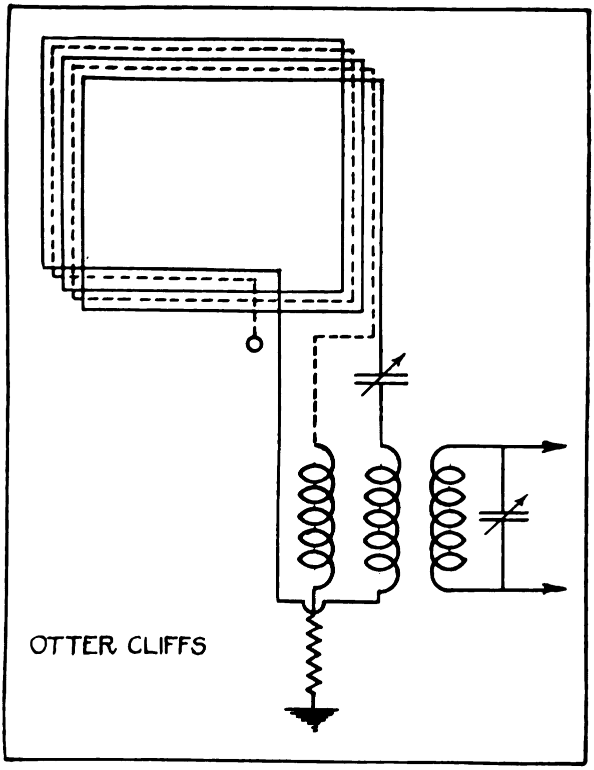

FIGURE 9

COMPARATIVE READING TESTS

During the last half of August and the whole of September, 1918, reading tests were carried on between the four stations mainly on the regular traffic from Nauen and Carnarvon. Belmar and Otter Cliffs, with their five receiving loops, were able to read simultaneously at any time during the twenty-four hours and took complete copy. Lakewood kept a twenty-four hour watch, switching from one station to another at intervals. The laboratory station was kept on this work during the afternoon, which was the most difficult time on account of the fading of the signals and the strength of the static, copy being taken from each of the two sending stations at frequent intervals. Carnarvon, being weaker, was more difficult to receive than Nauen, and therefore gave a more severe test of the static reducing qualities of the different receiving systems. On account of these different methods of carrying out the test at the different stations, it was somewhat difficult to arrange a plan for numerical comparison. As the afternoon was the most difficult receiving time and the only time during which all the stations received, it was finally decided to assume arbitrarily that reception during all hours from six at night to twelve o'clock noon would have been perfect. Then from the data[6] forwarded to this laboratory, calculations were made of the number of hours between twelve noon and six P. M., during which each station could have probably been received. Adding this to the eighteen hours of assumed perfect reception and dividing by twenty-four, we get the percentage of reception for the day. Table I gives the reception percentages for the four receiving stations for the August and September tests.

TABLE 1

AVERAGE PERCENTAGE OF RECEPTION

August 15-31

Receiving Station	Nauen Sending	Carnarvon Sending
Otter Cliffs	100 percent	98 percent
Lakewood	99 "	96 "
Laboratory Station	94 "	91 "
Belmar	94 "	81 "

September 1-30

Receiving Station	Nauen Sending	Carnarvon Sending
Otter Cliffs	100 percent	100 percent
Lakewood	100 "	98 "
Laboratory Station	100 "	98 "
Belmar	99 "	91 "

The improvement in the work of the laboratory station in September is in part due to changes in the circuit and in part to the general improvement in receiving conditions. It is believed that Table 1 gives a fair estimate of the static reducing qualities of the circuits used at Lakewood, Belmar, and the Laboratory Station. As has been explained, the good work of Otter Cliffs is largely due to its situation; and it is not to be assumed that the circuit used there, tho an excellent static reducer, is really superior to the other circuits.

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[6] No reports on Otter Cliffs reception were sent directly to the laboratory. The rating given is based on statements of the officers who examined the copy sent in by Lakewood and Otter Cliffs.

In estimating the value of the work on static reduction, it should be understood that with an ordinary antenna or even with a simple loop or underground or underwater antenna there are in most years, few if any days between June 15 and September 15 when a station like Nauen, to say nothing of weaker stations like Carnarvon, could be read at Washington thruout the twenty-four hours. Six or seven hours per day would probably be fair reception average for this time and even during the most favorable parts of the year there are many periods when reception is found impossible with the older methods.

OTHER TESTS OF THE CIRCUITS

Besides the comparative reading tests much work has been done at the Laboratory (River Station) in the endeavor to determine the actual amount of improvement produced by the various circuits. On account of the lack of space no attempt was made to set up a Weagant circuit.

The Taylor circuit has been extensively tested but has never given results comparable to those at Belmar probably because the proper decrement relation between the loop and water wire is only obtained in the water of high conductivity. (The water at Belmar is salt while that at the River Station is only moderately brackish.)

The Otter Cliffs circuit works well at the River Station but gives generally only about half the improvement in signal-static ratio produced by the Laboratory circuit. It has the great advantage however that it can be installed anywhere where a simple loop can be erected.

Table 2 shows some examples of improvement in signal-static ratio obtained with the Laboratory circuits under various static conditions. In the observations shown it appears that the improvement is greater the worse the original ratio. This is in part due to the tendency of the strong static to cover the signal and reduce its observed audibility. An extreme case of this is seen in the 3:00 P. M. observation of July 7th where the signal on the simple loop, tho evidently of some strength, is entirely inaudible thru the static. On the Laboratory circuit it was entirely readable. In other cases where the static is probably part of the fourth type, as on July 22nd, the improvement is slight.

Figure 10 reproduces a section of photographic recorder tape taken at Otter Cliffs in receiving from Lyons. It shows the effect on the readability of connecting and disconnecting the static reducing circuit.

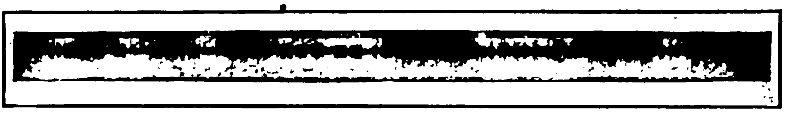

FIGURE 10

TABLE 2

EXAMPLES OF STATIC REDUCTION AT LABORATORY RIVER STATION

July 7, 1919
Lyons Sending

	Signal Audibility	Static Audibility	Ratio	Time
Simple Loop	6	4,000	0.0015	2:30 P. M.
Laboratory Circuit	36	150	0.24 (Readable)	2:30 P. M.
Simple Loop	Not heard thru static			3:00 P. M.
Laboratory Circuit	9	31	0.29 (Readable)	3:00 P. M.

July 11, 1919
San Diego Sending

Simple Loop	300	2,200	0.136	10:30 A. M.
Laboratory Circuit	58	245	0.236 (Readable)	10:30 A. M.
Simple Loop	140	1,200	0.117	11:40 A. M.
Laboratory Circuit	19	60	0.316 (Readable)	11:40 A. M.

Nauen Sending

Simple Loop	170	900	0.189	12:45 P. M.
Laboratory Circuit	80	250	0.320 (Readable)	12:45 P. M.
Simple Loop	12	1,200	0.01	2:00 P. M.
Laboratory Circuit	70	185	0.378 (Readable)	2:00 P. M.

July 22, 1919
Nauen Sending

Simple Loop	800	3,000	0.27	11:00 A. M.
Laboratory Circuit	40	80	0.50	11:00 A. M.

While the Weagant and Laboratory circuits showed the best records in the 1918 test, the Weagant adjustments were, according to last accounts, extremely difficult to make and the space required for the long loops (6 miles of 9.6 km.) was something of an objection. The Taylor and Laboratory circuits, tho very much smaller, require from 1,000 to 2,000 feet (305 to 610 m.), which precludes installation on shipboard and at some land stations. The Otter Cliffs circuit, on account of its compactness and simplicity, tho not the most efficient, has the widest application of the four.

The theoretical explanations of the static reducing qualities of the circuits are exceedingly incomplete. All the Navy circuits are very unidirectional and this undoubtedly explains some of their success in European reception, since in this part of the world, most of the first type of static (the most troublesome in summer) comes from the southwest. The balancing of the two directive systems of different decrements may also play a part and it is quite possible that we are also making use of factors not as yet recognized. At any rate the similarity of behavior toward the different types of static (easily eliminating the first type and having difficulty with the fourth) indicates that some of the important factors are common.

In conclusion, we may say of the four types of static enumerated at the beginning of this article: the first type, which is by far the most troublesome and common especially in summer, is found to be almost entirely eliminated by the new circuits. The second and third types in general cause little trouble. The fourth type, which causes most of the difficulty in reception now remaining, is reduced to a certain extent by all the systems, the Otter Cliffs circuit being perhaps the best of the Navy circuits in this regard. Mr. Weagant has recently reported in the paper already cited that he has obtained considerable success in its elimination.

The reduction in static described has naturally resulted in a marked improvement in European reception. Receiving at Washington with a simple loop or water wire, a high power transmitting station in Western Europe with an antenna current of approximately 300 amperes is unreadable for about 2,000 hours during the year. With any of the four static reducing systems, however, this time of unreadability can be reduced to less than 100 hours, or less than five percent of the time formerly lost.*

SUMMARY: The atmospheric disturbances of radio reception on the Atlantic Coast of the United States are classified as to type, effect, and probable origin. The static reducing systems of the Marconi Company (Weagant system), and of the Navy (Austin, Taylor, and Otter Cliffs systems) are described; and relative performance data of these are given. The improvement in reliability of reception to be obtained by the use of these systems is considered.

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*Thru an error, the discussion on the above paper has already appeared in the October, 1920, issue of the PROCEEDINGS, volume 8, number 5, beginning page 398. The readers of this paper are accordingly referred to the above citation.

THE MAGNETIC BEHAVIOR OF IRON IN ALTERNATING FIELDS OF FREQUENCIES BETWEEN 100,000 AND 1,500,000 CYCLES*

By

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PREFACE

This paper describes measurements of magnetization and core loss in iron, made by the author while a Lieutenant at the Signal Corps Radio Laboratories, Camp Alfred Vail, New Jersey.

The purpose of the work was a determination of the value of a sample of 0.002-inch (0.05 mm.) mild steel ribbon for use in transformers for radio frequencies.

The method employed in this investigation is not original. It has been described by Alexanderson in his paper on the "Magnetic Properties of Iron at Frequencies up to 200,000 Cycles."[1] However it is the belief of the author that the data obtained at the higher frequencies is new and also that the radio frequency voltmeter, as developed and described in this paper, is new and original.

The author wishes to express his thanks to the Officers of the Signal Corps Laboratories who so kindly secured permission for the release of the Signal Corps data and photographs for use in this paper. Especial thanks are due Lieutenant Donald G. Little for his generous and valuable assistance in the calculations. The enlisted men who built and arranged the apparatus assisted greatly by their thoroness and by their interest in the investigation.

The author desires to thank especially Professor L. P. Wheeler of the Physics Department, Yale University, for his criticism of this paper and suggestions for its improvement, and Professor C. F. Scott and Professor H. V. Bozell of the Electrical Engineering Department, Yale University, for their aid in the preparation thereof.

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*Received by the Editor, December 15, 1919.

[1] "Proceedings American Institute of Electrical Engineers," November, 1911.

INTRODUCTION

The measurements herein described are of two kinds:

Measurements of Magnetization.
Measurements of Core Loss.

METHOD AND THEORY

(a) MEASUREMENTS OF MAGNETIZATION.—These measurements consisted in observing simultaneously the current thru and the voltage across a toroidal winding containing the iron under test, at various frequencies and flux densities. These readings furnish data from which both H_{max} and B_{max} may be calculated.

H_{max} is given by the well-known relation

$$H_{max} = \sqrt{2}\frac{(0.4\,\pi\,n\,I)}{l}, \tag{1}$$

where $\frac{n\,I}{l}$ is the effective ampere-turns per centimeter length of the magnetic circuit.

B_{max} is given by the relation $B_{max} = \frac{E_{effect.}}{4.44\,f\,n\,10^{-8}A}$, (2)

where E is the effective value of the voltage induced in the winding by the changing flux in the iron, f is the frequency in cycles per second, n is the number of turns on the sample, and A is the cross-section area of the magnetic path in square centimeters.

It should be noted that the foregoing equations assume respectively a sine wave of current and a sine wave of emf. or flux. In the calculations this condition of simultaneous sine waves of current and flux has been assumed, altho the assumption is an approximation because of magnetic hysteresis.

(b) MEASUREMENTS OF CORE LOSS.—The core loss was measured by means of a voltmeter and an ammeter. Since for power measurements these instruments require the current and voltage to be in phase, a method which would satisfy this requirement had to be employed. The principle of the method is as follows:

A variable condenser and a variable inductance are added in series with the test sample. The voltmeter is connected across the combination. The inductance coil is set at its minimum value and the condenser is varied until the voltmeter reads a minimum for a given current in the circuit. The current and voltage are now in phase and their product equals the power consumed by the group.

To find the power consumed in the test sample alone, another reading is necessary. The test sample is either removed or short-circuited. This time the inductance coil is varied for minimum voltage across the combination. The product of the voltage so obtained and the current gives the power consumed by the auxiliary apparatus. The difference between the two measurements is the power expended in the test sample.

DESCRIPTION OF APPARATUS

ARRANGEMENT—The complete arrangement of apparatus is shown in Figure 1. The corresponding diagram of connections is given in Figure 2. The same nomenclature is used on both the photograph and the drawing.[2]

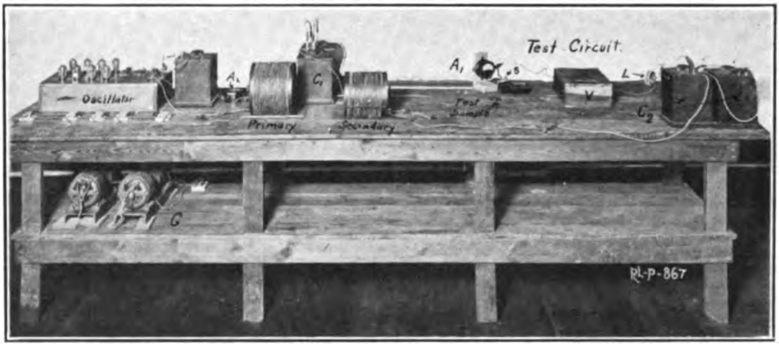

FIGURE 1

SOURCE OF POWER—The vacuum tube oscillator (1) shown at the extreme left in Figure 1 served as the radio frequency source of power. It consisted of 8 tubes arranged in pairs. A diagram of connections for one pair only is given.

The oscillator tubes used in this investigation were small ones designed for about 3 watts output. However as much as 7 watts per tube was developed in the test sample.

THE TEST CIRCUIT[3]—The arrangement of this circuit is shown in Figure 2. It will be noted that this circuit is entirely separate and distinct from the oscillator. This arrangement was made to secure greater flexibility and to provide a means for obtaining a coupling best suited for the efficient operation of the oscillator.

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[2] Details of the oscillator are recorded in the Appendix.

[3] Details of this circuit are recorded in the Appendix.

Energy was supplied to the test circuit thru the air-core transformer as shown. To reduce the losses to a minimum the transformer was wound with litzendraht wire.

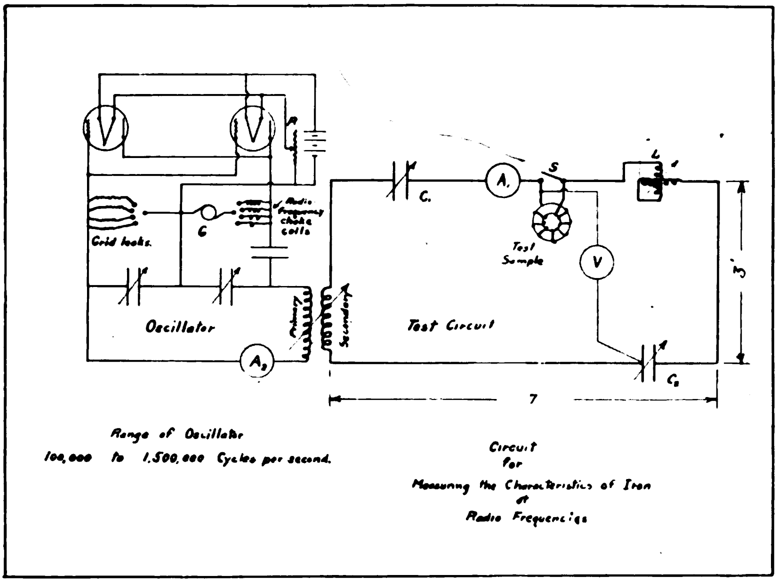

FIGURE 2

From Figure 2 it will be seen that the test circuit is considerably spread out. This was done to reduce the capacity of the sides of the circuit for one another, thereby securing a more nearly uniform current thruout the entire circuit. However, to insure measuring the current actually flowing thru the test sample an additional precaution was taken in placing the ammeter directly alongside of the sample.

The spreading out of the test circuit further served to prevent large electromotive forces from being induced in this circuit by stray fields from the oscillator and also to reduce the mutual inductance between parts of the test circuit.

THE TEST SAMPLE—The core of the test sample consisted of 20 doughnut-shaped laminations. These were punched from a mild steel ribbon[4] (annealed and enameled). The laminations were insulated from one another by thin paper in addition to their coating of enamel.

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[4] An analysis of this steel is recorded in the Appendix.

The outside diameter of the armature was [illegible] inches ([illegible] cm) and the inside diameter [illegible] inches ([illegible] cm). The [illegible] thickness of [illegible] in each armature was measured from an average of [illegible] readings to be [illegible] cm. ([illegible] inch).

[illegible] was [illegible] a [illegible] magnetic circuit [illegible] of the [illegible] sample [illegible]. This method of [illegible] was [illegible] the [illegible] of [illegible] winding [illegible] the [illegible] was [illegible].

The winding of the sample consisted of [illegible] turns of [illegible] wire* [illegible] wound around the core. The winding was separated from the core by a thin layer of paper.

MEASURING INSTRUMENTS

(a) *Frequency.* The frequency of the oscillations in the test circuit was measured by means of a resonant circuit of known constants calibrated in wave lengths. The circuit employed a [illegible] current indicator so that very little energy was required to operate it. The meter was checked against [illegible] standards of known accuracy so that its calibration was [illegible] accurate to one percent.

(b) *Current.* The current thru the sample was measured with radio frequency hot wire instruments. These meters were frequently checked by comparison with d. c. standards. Four meters of different ranges were used in order to obtain good scale deflections for all values of current. By these precautions a probable accuracy of 2 or 3 percent. was obtained.

(c) *Voltage.* The voltage across the sample was measured by a meter especially designed for use at radio frequencies. The development of this meter was undertaken with the purpose to secure: (1) a voltmeter which would be reasonably sensitive as compared with audio frequency instruments and (2) one which could be calibrated on direct current and be used at radio frequencies without further calibration or correction.

The use of a thermo-couple and galvanometer appeared to be an obvious way of satisfying the requirement as to sensitivity. For this purpose the instruments chosen (from those at hand) were a Western Electric thermo-couple (crossed wire type) and a Paul micro-ammeter. This combination gave full scale deflection with 3.5 volts across the heater of the thermo-couple, which had about 1,300 ohms resistance. The current taken by

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*Size: 32 strands of number 38 Brown and Sharpe gauge enameled copper wire.
Diameter of number 38 wire = 0.00397 inch = 0.0101 cm.

the combination is seen to be very small—less than 3 milliamperes for full scale deflection.

To test the instrument for use at radio frequencies the circuit shown in Figure 4 was employed. This circuit corresponds to the one in which the voltmeter was intended to be used. The meter was connected to measure the voltage drop across the resistance *A B*.

It was found that the meter continued to show a reading when *A B* was short circuited. This reading was about one-third full scale deflection and increased as the meter was moved nearer the side of the circuit marked *L*.

This phenomenon was apparently due to either the action of electrostatic forces on the sensitive needle of the micro-ammeter or to a displacement current flowing from the line *A B* to the line *L* thru the capacity existing between the micro-ammeter and the line *L*. This capacity is represented by the dotted condenser C_1. C_1 is shown connected to the terminal *G* because that is the terminal to which were grounded the metal top, internal shields, and the metal framework of the meter.

By further experiment without the thermo-couple but with the meter subjected to the same electrostatic forces as it had been with the thermo-couple, the action of these forces on the needle was found to be negligible. Therefore only the second explanation will be further considered. In this case the current is considered to flow from *L* thru C_1 to *G*, to the heater, from where it divides and flows to *A* and *B*. This current causes the thermo-couple to function in its normal manner, thus giving a deflection of the micro-ammeter.

Based on this reasoning a shield of copper foil was built around the instrument. It was made in the form of a box completely enclosing the meter, thermo-couple, and multiplier except for an opening in the top thru which the instrument might be read. This shield was electrically connected to *B* as shown in Figure 4 (b). With such an arrangement, the meter read the desired zero when *A* and *B* were at the same potential. However, when *A* and *B* were not at the same potential, two different deflections were obtained, depending on which way the voltmeter leads were connected to *A* and *B*. That is, on the reversal of its leads the meter gave an entirely different reading. On further experiment this difference in readings was found to increase with the amount of multiplier resistance.

These observations may be explained by the aid of Figures 4(b), 4(d), and 4(e). In Figures 4(d) and 4(e), R_m represents the multiplier resistance; R_H and R_c represent, respectively, the heater and couple resistances of the thermo-couple. Figure 4(b) assumes that the heater and couple make contact at their respective electrical centers. Actual measurements showed this assumption to be justified. Figure 4(d) shows the electrical equivalent

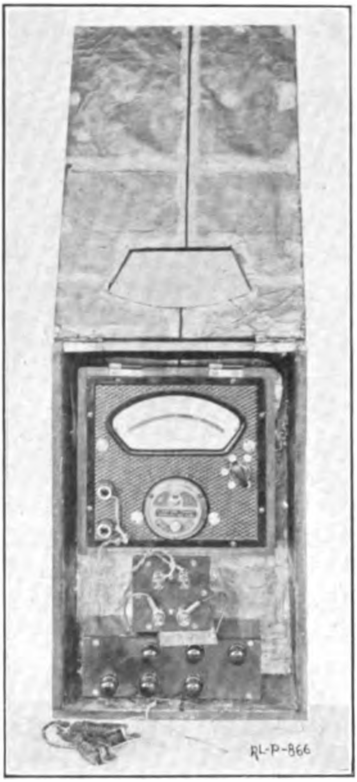

FIGURE 3

of the voltmeter as shown in Figure 4 (b). Figure 4 (e) shows the corresponding electrical equivalent when the voltmeter leads are reversed. By comparing these circuits it may readily be seen that for a given potential difference (alternating) between A and B, the heater current and therefore the meter reading would not be the same in each case. It may further be seen that when R_m equals zero, the two circuits are identical, and the meter may be expected to read the same on reversal. This conclusion was checked experimentally. By the same reasoning, it is clear that the voltmeter would read the same on reversal if R_m were split in half and each half connected in either lead to the thermo-couple. Altho such an arrangement satisfies the condition that the meter reading should not change on the reversal of its leads, it is seen on further consideration that the deflection for a given potential is a function of the frequency because the impedance of C_2 changes with the frequency.

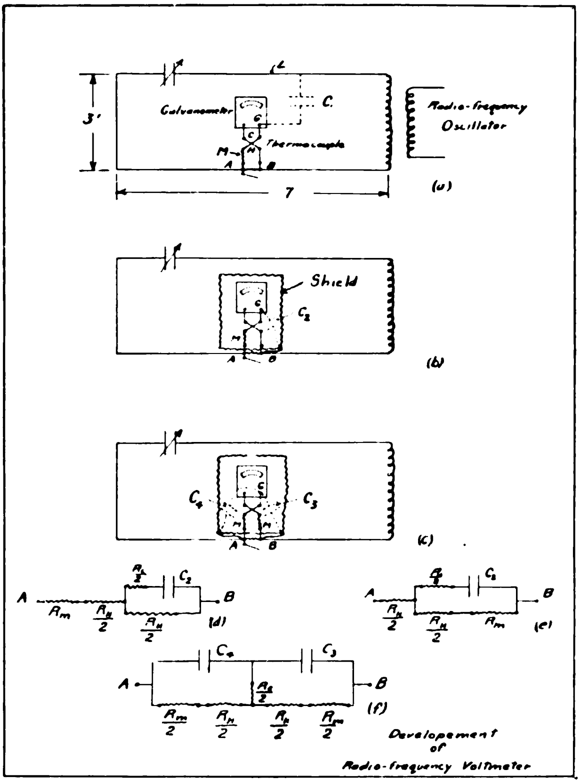

FIGURE 4

To overcome this latter difficulty the micro-ammeter was arranged to have the same capacity to both A and B. This was accomplished by splitting the original shield into two equal parts which were connected respectively to A and B as shown in Figure 4(c).

This circuit becomes a balanced a. c. bridge when $C_3 = C_4$

and when the resistances are balanced. In practice C_3 was made equal to C_4 by a symmetrical placing of the meter with respect to the two halves of the shield. The resistances were balanced by splitting R_m and connecting the halves as already described.

In Figure 4 (f) both the inductance and capacity between turns of the multiplier have been neglected. These factors must be small in order that the meter may be calibrated on d. c. and used at radio frequencies without further calibration or correction.

The inductance was made small by means of the bifilar winding.

The capacity between turns was reduced by means of a multipancake winding. Each half of the multiplier was wound on a cylindrical spool about 3 inches (7.62 cm.) long and 1 inch (2.54 cm.) in diameter. Each spool had 10 slots. Each slot contained about 4 feet of "prima-prima" wire (diameter 0.0015 inch) (0.0038 cm.) and resistance equal to 128 ohms per foot (or 420 ohms per meter). The spools were previously boiled in paraffin to eliminate moisture.

Altho the multiplier was found satisfactory, it is appreciated that much better windings might have been used. The foregoing method of winding was used because it was simple and required little labor, as the spools were already on hand.

The final test of the voltmeter for accuracy was performed as follows: A given value of current was sent thru a small diameter resistance wire at 3 different frequencies and the corresponding potentials across the wire were measured. The three frequencies were 0 or d. c.; 100,000; and 800,000 cycles. The resistance wire used was 4 feet (122 cm.) of number 40 "Therlo" having a resistance of about 120 ohms.[6] This wire was stretched out straight in air to permit a comparatively high value of current. The small sized wire was used to prevent errors due to skin effect.

The readings of the voltmeter on d. c. and 100,000 cycles were identical and the reading at 800,000 cycles was 1 percent. higher. At this high frequency, the ammeter was changed to the other end of the wire to eliminate errors due to stray displacement currents. However, the reading in this case was identical with the previous one. A part of this 1 percent. discrepancy at 800,000 cycles is accounted for by considering the inductance of the wire. From its calculated value an increase of voltage drop of 0.6 of 1 percent. would be expected.

The voltmeter in its final form is shown in Figure 3.

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[6] Diameter of number 40 wire = 0.00315 inch = 0.0080 cm.

PROCEDURE

MEASUREMENT OF MAGNETIZATION—Before each set of observations, careful adjustments were made of both the oscillator and test circuits in order that the current thru the test sample might approximate a sine wave as nearly as possible. These adjustments of course had to be consistent with a good transfer of energy into the test circuit.

The sharpness of the tuning of both the test circuit with the oscillator and the wave meter with the test circuit was used as a measure of the approximation to a sine wave of current in so far as that approximation is affected by the degree of coupling. That is, this method served to show whether or not the coupling between the circuits was too close, in which case the "double hump" would be present.

The oscillator was first tuned to approximately the desired frequency. Then the test circuit was tuned by means of the condenser C_1. The coupling between the test circuit and the oscillator was next adjusted for sharp tuning and good input to the test circuit. As the oscillator was now working under approximately final conditions, its grid leak and choke coils could now be varied for maximum output.

All these adjustments reacted upon one another so that several trials by the "cut and try" method had to be made.

The test sample heated considerably during the measurements. To save time two samples were used: one, for the preliminary adjustments, and the one to be tested, for the final adjustments. The one under test was immersed in an oil bath but even so, readings had to be taken quickly to avoid changes in the characteristics of the iron due to its rise in temperature.

The measurements of magnetization consisted in varying the current thru the sample by means of the plate voltage applied to the vacuum tubes, and observing the current thru the sample and the voltage across its terminals. The complete set of observations are shown in Figure 5.

MEASUREMENTS OF CORE LOSS—With some additions the same preliminary tuning was done in these measurements as in the foregoing ones. The inductance L was set at its minimum value, and the condenser C_2 was varied until the voltmeter V read a minimum for a given current. Changing C_2 of course detunes the test circuit which must be retuned by C_1. After several trials by the "cut and try" method the minimum reading of V was secured with the test circuit properly tuned.

The current thru the sample was next varied as previously described and readings were taken of the current and voltage. On the completion of these observations, the sample was short circuited and the circuit was retuned by increasing *L*, to replace the inductance of the sample. The correct setting of *L* was

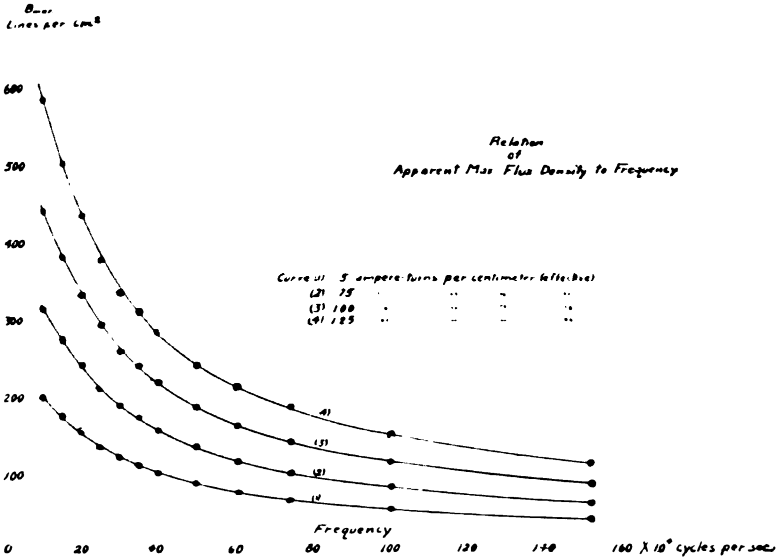

FIGURE 5

determined by the minimum reading of the voltmeter *V*. Another set of readings was now taken at the same current values as used in the previous set. The complete observations are given graphically in Figure 6.

DATA AND ERRORS

The accuracy of the instruments (wavemeters, ammeters, and voltmeters) has already been considered. There remains for further consideration the accuracy of the method itself, with possible corrections for certain known errors.

The measurements are shown to be quite consistent by Figures 5 and 6, especially as each point on any one of the four curves represents a new tuning and adjustment of the circuits.

Altho consistent results were secured over the greater part of the range of current values, it was difficult to get consistent readings above 1.5 ampere turns per centimeter. This lack of consistency was not due to the method however, but was due to the changing characteristics of the iron itself, as caused by heating. Both the permeability and resistivity of the iron increase with the temperature which causes a corresponding increase in the apparent permeability. Altho Figures 5 and 6 show consistency in the measurements, they do not show that the results may not be all too large or all too small; that is, they fail to show the presence or absence of consistent errors.

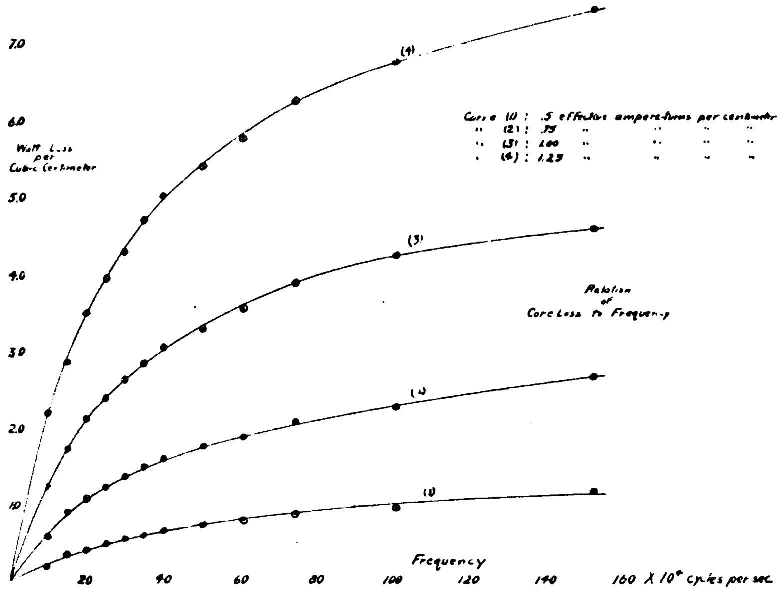

FIGURE 6

Among the consistent errors here considered are (1) those due to harmonics, (2) those due to the resistance of the winding on the test sample (the losses in this resistance are included in the losses in the test sample as measured), (3) those due to the leakage reactance of the winding on the test sample (the voltage induced in this reactance is included in the voltage measured across the sample), and (4) those errors due to the current taken by the voltmeter.

The following test made at one particular frequency shows at least for this one frequency that the second and third harmonics were very small in magnitude. A wavemeter was coupled with the test circuit and the fundamental wave length was measured. From this measurement the wave lengths of the second and third harmonics were determined.

The wavemeter was set accordingly to test for these two harmonics. No record of this test was made, but as the writer remembers only one of these harmonics was detected and the deflection of the current indicator was very slight. To get even this much indication the wave meter had to be coupled much more closely than it had been for the fundamental. No tests were made for higher harmonics. The foregoing test, coupled with the well-known fact that the harmonics generated by vacuum tube oscillators under average conditions are very small in magnitude, indicates that errors from this source may be neglected.

To find the magnitude of the resistance and leakage reactance of the winding of the test sample, an identical sample was constructed with a core of wood. The voltage across its terminals was measured at different frequencies and currents. These measurements are shown in Figure 7, with the impedance of the sample plotted against frequency. The resistance of the winding is shown to be negligible since the curve of total impedance goes very nearly thru the origin which would be the case if the impedance consisted of reactance alone, since the reactance is proportional to the frequency. The resistance would be expected to be small because litzendraht wire was used in the winding on the sample.

The reactance of the winding is not negligible, especially at the higher frequencies, where the iron is less effective. Here it produces an error of 10 to 15 percent.

Corrections have, therefore, been made in the measurements of magnetization. The corrected values were used for Figure 5.

In making these corrections the phase angle between the voltage induced by the flux in the iron and the voltage induced by the leakage flux was taken into account.

The true leakage reactance of the test sample probably differs somewhat from that measured by means of the dummy sample. However, as the correction is but a small percentage of the value corrected, considerable error in the correction may be entirely neglected.

It might possibly have been better to have used a test sample with a secondary winding and to have measured the voltage induced in this secondary. In this case the reactance drop could be neglected since the voltmeter current is so small. However on the basis of Alexanderson's experience, his method was considered sufficiently accurate and was, therefore, used, but, from the writer's experience, at the higher frequencies especially, the use of the secondary winding is recommended.

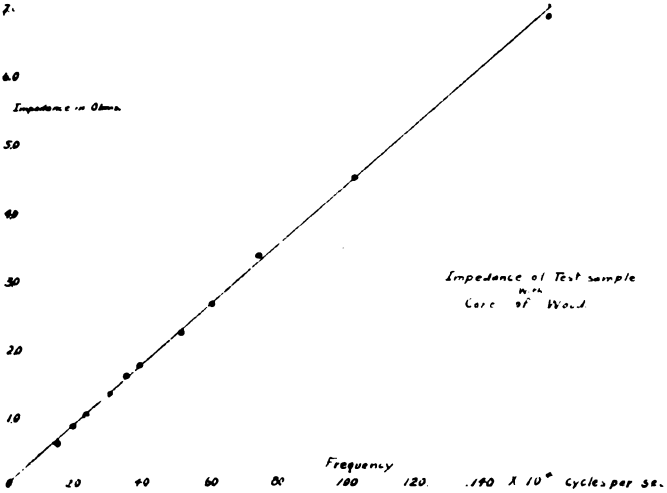

FIGURE 7

In considering the error due to the current taken by the voltmeter, there are two currents to be taken into account. The one is that current flowing thru the heater of the thermocouple, in phase with the voltage being measured. The other is the displacement current flowing between the halves of the shield around the instrument, 90 degrees out of phase with the voltage being measured.

The first current causes the largest error where this current is the greatest percentage of the current thru the sample, which is the case where the voltmeter was used without a multiplier (no multiplier was used for potentials below 3.5 volts), and where the voltage being measured is the highest for a given current thru the sample. Therefore, the maximum error, considering the heater current alone, occurs at the highest frequency, as may be seen from Figure 5, and at the lowest currents used. This maximum error is approximately 2.5 percent. At the lowest frequency the error is about 0.7 percent. Altho this error is appreciable, since it is small and occurs only at the smallest currents used, it has been neglected.

The error due to the displacement current is a maximum at the highest frequencies, since the impedance of the condenser formed by the shields is inversely proportional to the frequency; and at the highest currents, since the voltage across the sample per unit current is here the greatest. From the capacity between the shields, which was found to be about 75 micro-micro-farads,[7] the error calculated for the highest frequency and highest current (Figure 5) was found to be 2.7 percent. As this error, altho appreciable, is the maximum error and occurs only at the extreme limits of frequency and currents used, it has been neglected. Below 750,000 cycles the error is everywhere less than 1 percent, which is entirely negligible.

The error due to the total voltmeter current is a maximum at the highest frequency and lowest current and is equal to about 3.5 percent.

Since the errors due to the current thru the voltmeter are appreciable only at the extreme limits of the measurements, where the accuracy of the results as a whole is the least, these errors have been neglected.

It is the belief of the writer that the accuracy of the results as a whole compares favorably with the accuracy that might be obtained at frequencies of 60 cycles.

CONCLUSIONS

It will be remembered that equations 1 and 2 are based on the assumption of simultaneous sine waves of both the current and flux in the sample, which assumption, of course, holds only over the straight part of the saturation curve. From Figure 8, which shows the radio frequency saturation curves, it may be seen that the iron was not nearly saturated, even at the highest values of magnetization and highest frequency. The assumption in equations 1 and 2, therefore, appears to be justified.

From the curves shown in Figures 8 and 9 data was taken for the curves plotted in Figures 5, 6, and 10, which show, respectively, the variation of losses, apparent flux density, and permeability with frequency.

To calculate the depth of penetration of the magnetism into the iron the following relation has been used by Alexanderson and others:

$$l_p = \frac{1}{2}\frac{\mu_a}{\mu} t \qquad (3)$$

---

[7] Measured by the Measurements Group of the Signal Corps Laboratories.

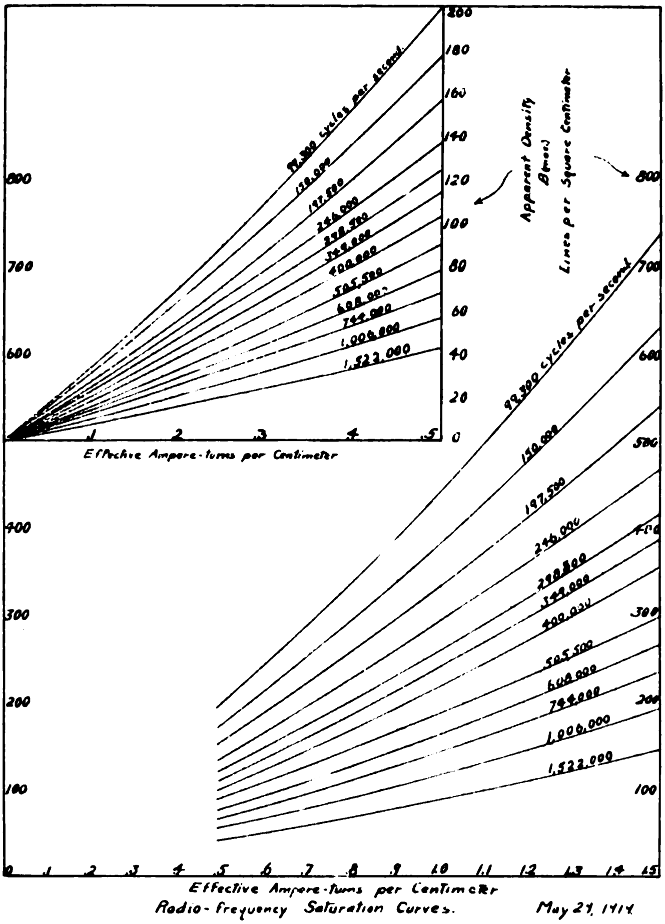

FIGURE 8

where l_p is the depth of penetration, μ_a is the apparent permeability, μ is the true permeability and t is the thickness of each lamination. In this equation the true permeability is considered to remain unchanged at radio frequencies and the apparent permeability is considered to be less than the true permeability for the reason that only a part of the iron is effective. The effective thickness of iron on this basis is equal to $\frac{\mu_a}{\mu} t$. The factor $\frac{1}{2}$ enters equation (3) because the magnetism penetrates both surfaces of the lamination.

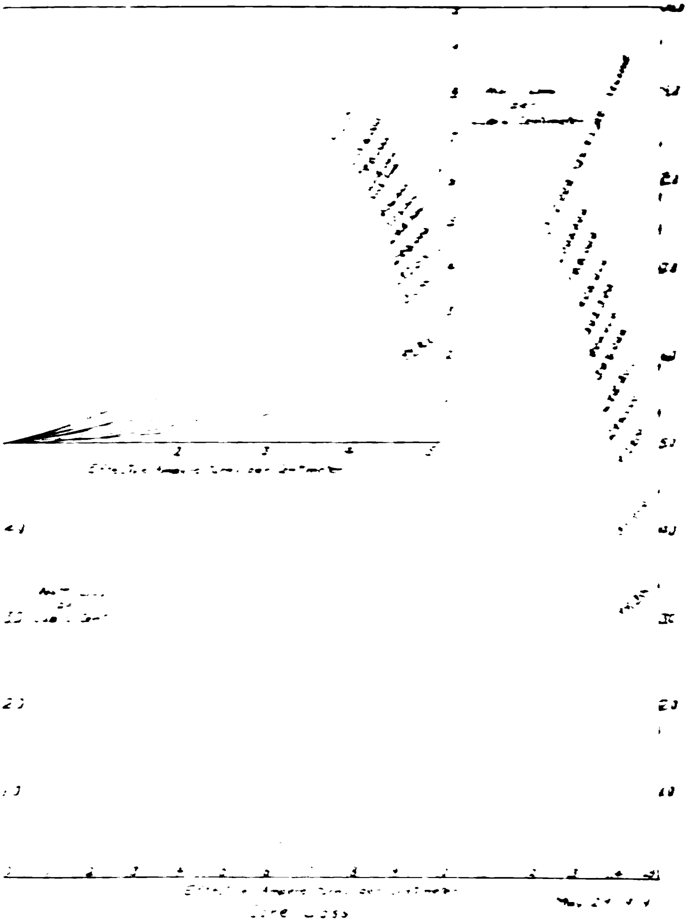

FIGURE 9

For μ a value of 2 250 was assumed, there being no information at hand as to the true value and this being the value used by Alexanderson for this iron. The depth of penetration as thus calculated is plotted in curve 2, Figure 11.

For comparison the value of penetration was calculated according to Steinmetz's formula:

$$l_p = \frac{3570}{\sqrt{\lambda \mu f}} \qquad (4)$$

where λ is the electric conductivity of the iron, μ is the true permeability, and f is the frequency in cycles per second. Here

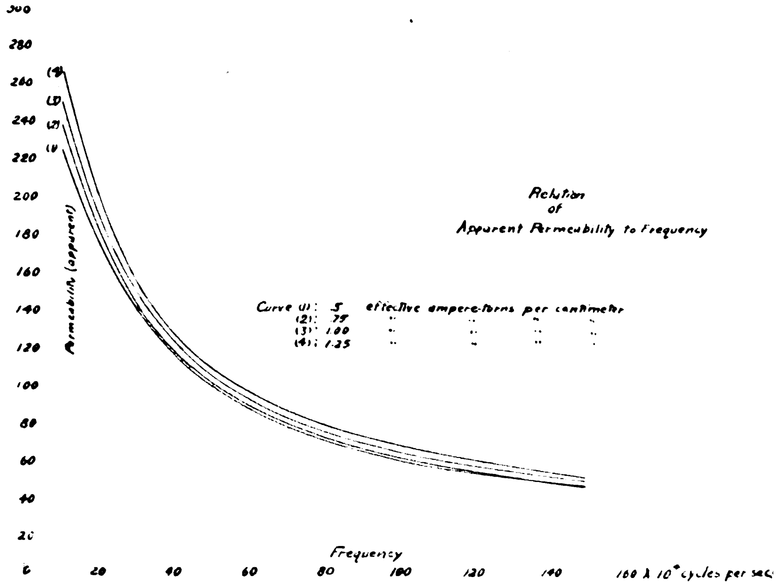

FIGURE 10

again μ was assumed to be 2,250. λ was measured to be 0.67 $(10)^5$. The calculated depth of penetration is plotted in Figure 11.

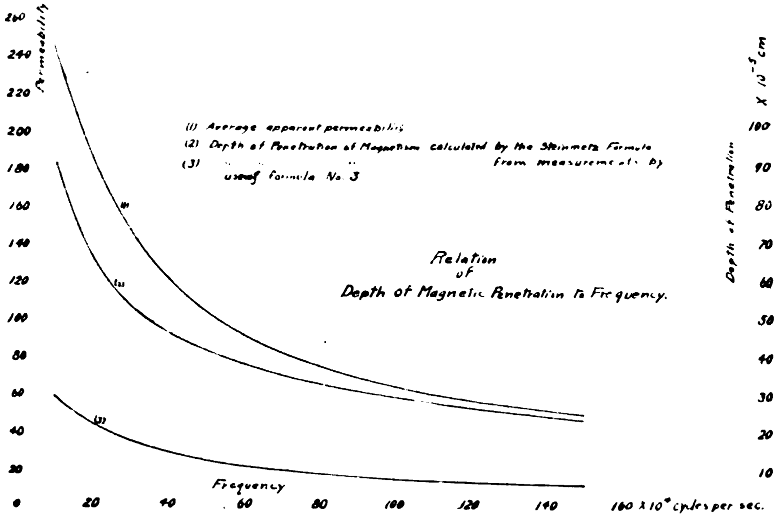

FIGURE 11

This value is seen to be about triple that obtained by the use of equation (3). Alexanderson found a similar discrepancy in the same direction but less in magnitude, and offered as a possible explanation that additional skin effect was caused by the slight gap between laminations in the sample used. This explanation cannot be applied in the present case where each lamination formed a complete magnetic circuit.

The present comparison of equations (3) and (4) is, of course, crude since the value of μ was not measured and λ was measured from only a single sample about 0.5 inch (1.27 cm.) wide and 2 feet (61 cm.) long (in the direction of rolling). However, it is unlikely that errors in these two factors would account for the entire discrepancy, in which case there must be some other explanation. What this explanation may be the writer is not prepared to state.

At the values of frequency and current where this investigation overlaps that of Alexanderson, a comparison of results shows that about 25 percent (very approximately) higher flux density and core loss in the present investigation.

Assuming that the apparent permeability is inversely proportional to the thickness of laminations, an increase of flux density of about 40 percent would be expected, since Alexanderson used iron 0.0076 cm. (0.003 inch) thick while the writer used iron 0.0054 cm. (0.002 inch) thick. The results, however, are essentially in agreement.

The following observations may be of interest. They were made during the calculation of the corrections made in the magnetization measurements for the leakage reactance of the winding on the sample. The power factor of the sample was involved in these calculations. The power factor was seen to increase with the ampere turns to a marked degree at the lower frequencies, but to a very small degree at the higher frequencies. Also the power factor increases with the frequency and approaches a value of approximately 0.7 at a million cycles. It is interesting to compare this latter observation with Steinmetz's statement: "The lag of the apparent permeability represents an energy component of emf. of self induction due to the magnetic flux, which increases with increasing frequency and ultimately becomes equal to the reactive component."

Since the curves of the depth of penetration show that such a minute depth of iron is actually magnetized, the need for thin iron is strongly emphasized. Also since the depth of penetration increases with the electrical resistivity of the iron, this quantity should be large.

As it is a well-known fact that iron does not lose its permeability at radio frequencies and since there is a growing need for the use of iron at these frequencies, the problem of securing satisfactory iron becomes important. This problem appears to resolve itself into a metallurgical or chemical one: namely that of producing extremely thin iron of high resistivity.

The development and testing of such iron would be a very interesting problem for future research.

The development of formulas for the calculation of flux densities and losses at various frequencies and magnetizing forces and for different kinds and thicknesses of iron also offers a most interesting and practical field for future research.

For such investigation the standardization of the dimensions of the test sample is desirable.

SUMMARY: Mild steel ribbon, 0.002 inch (0.05 mm.) in thickness, was tested at various radio frequencies between 100,000 and 1,500,000 cycles per second for the relation between ampere turns per centimeter and flux density, and for core loss in watts per cubic centimeter at the various frequencies. A vacuum tube oscillator supplied the necessary current for magnetizing the ring samples of steel. The method of measurement required the development of a precision radio frequency voltmeter, which is described in detail. All the results obtained are shown in graphic form.

APPENDIX

THE OSCILLATOR

(1) Filament Battery Potential, 10 volts.

(2) Filament Rheostat Resistance, 2 ohms.

(3) Grid Leak Resistance, 1,000 to 30,000 ohms in 1,000-ohm steps.

(4) The grid and plate condensers were approximately equal in their capacities, which ranged from 0 to 30,000 $\mu\mu$f. each by means of 6 Dubilier mica condensers of 5,000 $\mu\mu$f. each.

(5) Range of hot-wire ammeter A_2, 0 to 15 amperes.

(6) The primary of the oscillation transformer consisted of 24 turns of litzendraht wire (size: 32 strands of number 38 wire) wound on 6.75 inches (17.1 cm) of bakelite cylinder 8.25 inches (2.1 cm.) long and 10 inches (25.4 cm) in diameter. Taps were brought out for each turn.

(7) Source of plate current. The source of plate current was two Westinghouse motor generator sets shown in Figure 1. For small values of power one of these was used alone. For

high values the machines were connected in series, in which case a voltage of 900 or 1,000 volts was impressed on the tubes.

(8) The vacuum tubes used were Signal Corps type, VT 12. This type of tube was used because of its ability to stand overloading. These tubes will operate with their plates white hot without gas appearing.

THE TEST CIRCUIT

(1) The secondary of the oscillation transformer consisted of 24 turns of litzendraht wire (size: 32 strands of number 38 wire) wound on 6.75 inches (17.1 cm.) of a bakelite cylinder 8.25 inches (21.0 cm.) long and 8.5 inches (21.6 cm.) in diameter. Taps were brought out for each turn.

(2) Condenser C_1, 500 to 25,000 $\mu\mu$f.

(3) Range of hot-wire ammeter A, $0-0.3$ amperes, $0-0.6$ amperes, $0-1.0$ amperes, and $0-3.0$ amperes.

(4) The Variometer L.

(a) The first variometer used consisted of a stationary cylinder 1.37 inches (3.49 cm.) long and 3.06 inches (7.73 cm.) in diameter wound with 20 turns of litzendraht wire (size: 32 strands of number 38 wire) and a rotating cylinder 1.37 inches (3.49 cm.) long and 2.18 inches (5.56 cm.) in diameter wound with 20 turns of the same size litzendraht as the stationary coil. The two coils were connected in series and the impedance of the variometer was varied by rotating the secondary with respect to the primary.

(b) A second variometer having a smaller minimum impedance than the first consisted of an outer and stationary cylinder 0.75 inch (1.91 cm.) in length and 5.0 inches (12.7 cm.) in diameter wound with 8 turns of litzendraht wire (size as before). The inner rotating cylinder was 0.75 inch (1.91 cm) long and 4.25 inches (10.8 cm) in diameter. It was wound with 10 turns of litzendraht wire (size as before).

(c) For the highest frequencies where the inductance of the test samples become very small this latter variometer was changed to 3 turns on the stationary coil and 5 turns on the secondary.

(5) Condenser C_2, 3,000 to 100,000 $\mu\mu$f.

(6) Voltmeter V Ranges: 1.0 to 3.4 volts (no multiplier), 3.0 to 10.5 volts low range of multiplier, 8 to 27 volts middle range of multiplier, and 17 to 60 volts high range of multiplier.

TEST SAMPLE

ANALYSIS OF STEEL—An analysis of steel similar to that used for the test sample is as follows:

	Percent.
Carbon	0.09
Silicon	0.025
Molybdenum	0.006
Phosphorus	0.004
Titanium	Trace
Chromium	Trace
Vanadium	None
Nickel	None

This analysis was made by Professor Frank W. Durkee, Tufts College, Massachusetts, for the American Radio and Research Corporation, Medford Hillside, Massachusetts. Thanks are due Dr. V. Bush for the use of this material.

DISCUSSION

N. W. McLachlan (by letter): In the preface to Mr. Wilson's paper, it is stated that the data are new. The actual numerical values for a certain thickness of iron and a certain range of frequency are undoubtedly new, but no new facts have come to light regarding the behavior of iron at high frequencies. From the absence of references in the paper, one would conclude that no investigations had been conducted on the behavior of iron at radio frequencies since Mr. Alexanderson's brilliant experiments of 1911. This, however, is not the case. The "Year Book of Wireless Telegraphy," for 1918, contains a complete résumé of work on iron at radio frequencies under undamped oscillations, up to October, 1917, together with a list of 45 references. Since this article was written, work on the same subject has been published in France and in Germany. In the "Journal of the Institution of Electrical Engineers" for April, 1916, a paper is published giving details of experiments on iron of different quality and thickness up to frequencies of 10^6 cycles per second. At that time the thinnest material available in England was 0.25 millimeter (0.01 inch).

Mr. Wilson's results are probably quite accurate enough for most practical purposes, for it is seldom, if ever, that iron is used in practice under the same conditions as those which hold in the laboratory. I am, however, not prepared to agree with the statement in which he claims the same order of accuracy at frequencies of a million as at 60 cycles per second. A calibration of hot wire ammeters by direct current is no guide to their behavior at radio frequencies. The current measurements could have been carried out to a high degree of accuracy by using an iron-cored current transformer[1] and a thermo-ammeter. It is possible to calibrate accurately the current transformer at radio frequencies by using a separate heater, thermo-junction and a sensitive direct current galvanometer.[2] I have built current transformers with errors less than 1 percent at frequencies from 10^5 to 10^6 cycles per second.

Mr. Wilson has found the usual discrepancy between the calculated and experimental values of the depth of penetration of magnetization, or as it is frequently termed, the "equivalent depth of uniform magnetization." The reason for the difference is probably due to the fact that the resultant magnetizing force operative on the iron decreases from the skin to the centre of the plate. Thus the flux density, as is well known, decreases from the skin to the centre, since the so-called "true" permeability of iron varies with the flux density. It follows, therefore, that the "true" permeability varies from the skin to the centre. Moreover, the propagation of the flux waves within the iron, and the shape thereof, is quite different from that contemplated in the mathematical analysis, in which the permeability is assumed constant thruout the plate. Even when the phase displacement due to hysteresis is taken into account (with constant permeability), the discrepancy is still large. When the variation in permeability is considered, the variable hysteresis loss at different depths complicates the problem still further.

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[1] "Electrician," December 22, 1916; "Wireless World," July, 1917.

[2] "Proceedings of the Royal Society of London," 1914.

The question of a sinusoidal current wave giving rise to a sinusoidal voltage wave is a point which can be settled only experimentally. At low frequencies there is considerable distortion of the voltage wave form, and at high flux densities the wave is very peaked.[3] In this respect it would be extremely interesting to see exactly what does happen at high frequencies. Such an investigation could be conducted by using an apparatus similar to that developed by the French military authorities and known as the Dufour cathode ray oscillagraph. This instrument has been used to record oscillations of 7.5×10^5 cycles per second, generated by triodes.

Leon T. Wilson (by letter): In Dr. N. W. McLachlan's discussion, it is stated that "the actual numerical values for a certain thickness of iron and a certain range of frequency are undoubtedly new, but no new facts have come to light regarding the behavior of iron at high frequencies." This interpretation of my statement, that the *data* are new, is the correct and only one which I thought would be made. The chief novelty consists in the voltmeter employed and not in the data obtained, which are offered only as being of some possible general interest.

From the absence of any, except the necessary references in my paper, Dr. McLachlan would draw the conclusion that no investigations had been conducted on the subject since the experiments of Mr. Alexanderson in 1911. My paper, as may be seen from the first sentence of the preface, is not intended to be a historical résumé of all work previously done on the subject. The need for such a résumé was so well fulfilled by Dr. McLachlan's own paper contained in the "Year Book of Wireless Telegraphy," for 1918, that I considered it entirely unnecessary even to attempt to add anything further.

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[3] "Journal of the Institution of Electrical Engineers," June, 1915.

Objection is made, and not without grounds, to my statement that the accuracy of the results as a whole compares favorably with the accuracy that might be obtained at frequencies of 60 cycles. Here I had in mind the accuracy of measurements as they are very generally made at 60 cycles, and not that accuracy which it is possible to obtain in the laboratory under the best conditions. That is, the statement should not be interpreted as claiming a high degree of accuracy.

Dr. McLachlan has made some interesting comments concerning current measurements, using an iron-cored transformer and thermo-ammeter. The use of such a refinement in the current measurement in the present investigation, without having gone to similar refinements thruout, which would have been rather difficult in view of the changes in the properties of the iron with changes in temperature, reminds one of the old adage about "straining at a gnat and swallowing a camel."

Dr. McLachlan's explanation of the usual discrepancy between the calculated and experimental values of the depth of penetration is constructive and of general interest. The reason for bringing out this point in the paper was to show that the discrepancy could not be explained as due to the presence of an air gap in the test sample.

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CENTRAL STATIONS FOR RADIO COMMUNICATION*

By

ERNST F. W. ALEXANDERSON

(CHIEF ENGINEER, RADIO CORPORATION OF AMERICA; CONSULTING ENGINEER, GENERAL ELECTRIC COMPANY)

Radio achievements are often referred to as belonging in the realm of mystery, and it is indeed wonderful that we are now able to speak with a voice that carries thru empty space across the oceans. Whenever knowledge conquers a new force of nature for the use of humanity, it ceases to be a mystery, but the pursuit of this knowledge makes an even greater appeal to the imagination.

The development of the steam engine was a triumph of the engineering art of the last century, but it was not the engine itself but the steamship and the locomotive that interested humanity.

The telephone and cables no less than the steam engine have introduced a new era in human affairs. They have, to a degree, conquered space and time, but only with certain serious limitations.

An ocean cable runs only from one landing place to another and it can be cut in time of war; its use can be censored by its owners and controlled by military and naval power. When, on the other hand, you send a radio message, it may reach all parts of the world. Depending upon whether it has been sent in code or in plain language, it may be a confidential, private message or a press message intended for the world at large, but nobody can directly prevent the electromagnetic waves themselves that carry the message from reaching their destination. It is thus not exaggeration to say that the emancipation of the human spirit that was begun by the invention of the printing press has found its fulfilment in radio communication. Radio makes the transmission of ideas from man to man and from nation to nation independent not only of any frail material carrier such as a wire, but above all it renders such communication independent of brute force that might be used to isolate one part of the world from another.

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These are the ideal aims which inspire the engineers engaged in the development of the radio technique. This is also the explanation why some of the foremost lawyers, executives, financiers, officials, and statesmen of this country have found incentive in the human aspects of the radio technique to devote a great deal of their time and thought to its promotion and development on a world-wide scale.

The interest that is evidenced by all concerned in this subject has become much more serious since it has been established that the laws and forces with which we are dealing are within the control of our knowledge, so that engineers can now proceed with the design of a radio communication system with practically the same deliberate accuracy as in the design of an electric power transmission from a water fall to a railroad.

This audience is constituted of members of a society of electric power and light engineers as well as members of THE INSTITUTE OF RADIO ENGINEERS; so I shall take the opportunity to trace the close connection which now exists between electric power engineering and modern radio engineering and will demonstrate, as the specific subject of this paper, how the development of the Central Station for radio communication is as logical and inevitable as was the development of the central electric power station.

The entry of the Corporation with which I have been connected for the last twenty years upon the field of radio communication has been a gradual growth and a natural consequence of its general activities in power engineering. The engineers specializing in alternating current technique were in a natural position to take up the problem of designing alternators and transformers in the radio technique. These differ from the one used in the power technique principally in the fact that the number of alterations per second is about one thousand times as great. This speeding up of the performance one thousand times involved many new problems, but the most remarkable fact to record is that *the generally established principles of the alternating current power technique could be applied to the radio technique almost without change.* It meant that the magnetic properties of iron which had been reduced to an exact science by Steinmetz thirty years ago had to be studied again at radio frequencies; but it was found the Steinmetz laws of hysteresis eddy currents, and skin effect were as accurate at two hundred thousand cycles per second as at twenty-five cycles.

It was furthermore found that the established conceptions of phase displacement, power factor, and leading and lagging currents were as applicable and useful in the high frequency as in the lower frequency technique.

It is true that radically different methods had to be devised for measuring power factors of a fraction of one per cent from the methods used for measuring power factor of 50 to 100 per cent, but the new methods of investigation verified the well-known principles.

The starting point of this development work was the time when Fessenden brought to the General Electric Company the problem of generating alternating currents for radio transmission. In doing so Fessenden realized that a practical solution of this problem could be worked out only by an organization of specialists.

Some of the problems that presented themselves in the evolution of the radio power plant were:

The design of a dynamo-electric machine or alternator generating electric power in the form of alternating currents of frequencies one thousand times as great as those used for motors and lights.

The development of magnetic amplifying devices capable of translating telephone and telegraph currents into corresponding modulations of the radio frequency energy flowing from the power plant into the radiating antenna.

The development of a regulator so sensitive as to hold the speed of an ordinary induction motor constant within a few hundredths of one per cent, this being necessary in order to maintain the proper phase relations in a load circuit working at one-third of one per cent power factor.

Improvement of the tuning of the antenna so as to transform as large a part as possible of the generated energy into electromagnetic waves.

The realization of Fessenden's vision, the radio power plant of to-day, became thus the result of the combined effort of leading electrical and mechanical engineers. Among these, it is sufficient to mention Mr. W. L. R. Emmet, the creator of the giant electric power stations of today.

The radio power plant which resulted from this was shown to Senator Marconi during a visit to Schenectady, and because of his interest in its performance, it was transferred to the Marconi Radio Station at New Brunswick, where it had no sooner been installed than it was taken over for war service by the Navy. Further enlargements and developments of this installation which were undertaken by the Navy resulted in the plant which is now owned and operated by the Radio Corporation of America.

Here we had arrived at a point where two schools of engineering pursuing different aims, with widely different modes of thought, had been brought before a common problem. The one had been thinking in terms of power factor, kilowatts, and phase displacement, the other in terms of wave length, decrements, and tuning.

A third school of knowledge was at that time brought into contact with this technique and added new impetus to it. As soon as such scientists as Drs. Coolidge and Langmuir began to study the Fleming value and the remarkable little device invented by Dr. Lee De Forest and known as the audion, the foundation was laid for the vacuum tube technique which has so profoundly influenced the art of radio communication.

These scientists tell us that electricity is not the mysterious "power fluid" that we may have imagined flowing smoothly in our wires, but miniature plants or comets of condensed material electricity of definite charge and mass shooting across a miniature universe inside of a glass bulb and following orbits that can be calculated as accurately as the orbits of the stars.

Keeping in mind the origin of the modern art of radio communication in these three widely separate realms of knowledge, power engineering and electro-physics, we may now proceed to examine the essential parts. We find then—first, a modern electric power plant working at very high frequency; second, a network of wires a mile (1.6 km.) long, supported on tall masts; third, on the opposite side of the ocean a little glass bulb full of shooting stars. The question is: what does really happen?

Does the electricity generated by our alternator emanate from the antenna and flow in an undulating stream thru the air or thru the water or thru both? If we search for it in an airplane, we find it, and if we submerge ourselves in a submarine and search for it, we find it, and yet we are told it is not so.

Does the little electron, as an individual, take a leap off the aerial wires and, after devious paths, find its home in the glass bulb on the other side of the ocean? We are also told that it does not.

If I knew exactly what really does happen, and should try to tell you, then sooner or later somebody would claim that I was altogether mistaken. Therefore, I will only try to tell you how I imagine that it happens, wondering if any of you will see the same mental picture of the process that I see.

We were once told by the physicists that all space was filled by a fine substance that was called ether, and that the light and heat that radiated from the sun was a wave motion in the ether. The physicists now tell us that there is no ether, but still they say that light is a wave motion. Be this as it may, for the purpose of visualizing what takes place in radio transmission, it is convenient to cling to the theory of the ether.

We are familiar with other forms of wave motion—the air waves that carry sound to our ears and the water waves on the ocean. Thus the carrier of the radiated electric energy must not be likened to the flowing stream of water, or to the wind or to a bullet shot from a gun, but likened to a wave in a uniform medium where each particle of the medium oscillates around a stationary base line while the wave rolls forward.

The distance that a wave can travel in an absorbing medium before it fades out to a definite extent is proportional to its length. We may therefore introduce the idea of wave length, which is the distance from the crest of one wave to the next. The long swells of ocean travel for hundreds of miles, whereas a pebble dropped on a still surface of water produces a ripple that fades away in a short distance.

In radio communication it has been observed that the distance over which reliable communication can be maintained is about 500 times the length of the ether wave that is used. It may be more than a mere coincidence that the distance to which a sound wave travels in air, and a wave on the surface of water will travel before it fades out, is also about 500 wave lengths. The average wave length of sound of spoken words is about one foot (0.3 m.), and we know that if we speak loudly our voices will carry a distance of about 500 feet (150 m.). The exceptions to this rule that will occur to anybody are also significant. We know what distances voices will carry over a lake in a quiet evening. We also know what extraordinary distances radio signals will carry sometimes in a quiet night. These are "exceptions that prove the rule," and the rule refers only to reliable communication under normal conditions.

A radio transmitting system is designed for the purpose of producing waves in the ether which we call electromagnetic waves, and for controlling the rate at which the waves are produced in such a way that a train of successive waves will carry the meaning of articulate speech or telegraphic code. If we wish to send a message a long distance, we must select a long wave. The distance to Europe is 5,000 kilometers (3,200 miles). If this distance is to be bridged by 500 wave lengths, each wave length must be at least 10 kilometers (six miles), or, as it is usually expressed, a wave length of 10,000 meters.

We can produce water waves by rocking a boat. If we rock a canoe rapidly we get a short wave, but if we rock a larger boat more slowly we get a correspondingly longer wave. To rock the boat requires energy, but in order to produce a wave of suitable length, the energy must act thru an intermediate member which has suitable size, proportions and period of oscillation.

In radio transmission the energy is furnished by the radio frequency power plant, but, in order to transform this energy into waves, there is required the intermediate member which makes contact with a large volume of the medium which carries the wave motion. This medium is the ether and corresponds to the water or the air in the more familiar forms of wave motion. The member that transforms the energy to the ether is the antenna. The waves used for trans-Atlantic communication are as a matter of fact 10,000 meters long, or even longer. The antenna corresponds to the hull of the rocking boat or the sounding board of the piano.

The analogy with water waves may be carried still further. The wave is a successive displacement of the medium, and the initial displacement produced by the member acting upon the medium is proportional to its volume. The water displacement of the boat corresponds to the effective volume of the antenna. The maximum voltage at which the antenna can be operated corresponds to the maximum angle to which the boat may be rocked before it ships water. This is the voltage at which the surrounding air breaks down under the electrostatic pressure. In electrical units, the displacement in the ether is expressed in meter-amperes. This is really a measure of volume as is apparent from the consideration that the amperes charging current at the limiting voltage is proportional to the two horizontal dimensions. The third dimension or the height appears directly in the product, and is expressed in meters.

The height of the antenna is the most expensive of the three dimensions by which we may create electric displacement in the ether. The tendency in stations designed for greatest economy is, therefore, towards structures of moderate height and great length, whereas, the tendency in the past, when dynamic efficiency was the principal consideration, was towards towers of great height. The unit of performance on the old basis was kilowatts consumed by the antenna. The unit on the new basis is "ether displacement." This modern measure of antenna radiating capacity is the number of meter-amperes of "ether displacement" that can be produced at the voltage which is limited by the breakdown of the air.

The antennas of the stations of New Brunswick and Marion which are now used in trans-Atlantic service are each one mile (1.6 km.) long. In the new Radio Central Station, which is being built by the Radio Corporation on Long Island, there will be ten or twelve antennas, each a mile and a quarter (2 km.) long. This station is intended to communicate efficiently with all parts of the world. When very long distances are to be spanned, correspondingly long waves will be used. For efficient transmission of these long powerful waves, an antenna will be needed that makes contact with a large volume of ether. This will be accomplished by combining several of these antennas into one unit. At other times the same antennas will be used for the simultaneous transmission of several messages over shorter distances.

The shifting of radiation power which has been referred to is made possible by the use of the multiple tuned antenna which has been described in a previous paper before THE INSTITUTE OF RADIO ENGINEERS.[1] The New Brunswick and Marion antennas are now tuned so that each acts as six single antennas operating in multiple. The combining of several such groups in multiple is only a further extension of the same principle.

When two such antenna groups are connected in multiple, the loss resistance is reduced to one-half. Hence the efficiency of the antenna is increased so that a given power produces more radiation. Still more important is, however, the fact that more power may be utilized at this increased efficiency, and so the net result is that the amplitude of the radiated wave is doubled, which means that four times as much energy is radiated.

The economical factors that point to the radio central station as the practical solution of the problem of long distance communication are practically the same as those that created the central electric power station. Broadly speaking, they provide for the utilization of the plant investment and operating force to the utmost by shifting the equipment from one service to another and combining it to meet various demands.

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[1] See PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 8, number 2, pages 279–282.

New York is a natural communication center and the service must extend to Europe, South America, and westward. Another Radio Central Station at Hawaii is being equipped to serve as a relay for all points on the other side of the Pacific Ocean.

While it is winter on the northern hemisphere, the radiating power to Europe can be much reduced, but this is the season when the South American traffic requires a maximum radiation because of summer conditions then existing on the southern hemisphere. The New York Radio Central Station can then divert some of its radiating power from the European to the South American circuits. There will also be daily fluctuations in traffic load which will occur at different hours due to the difference in geographic longitude. Thus the peak load of European traffic will occur at different times than the South American and Western traffic. The central station equipment can be utilized so as to take advantage of this.

The realization of trans-Atlantic radio telephony for commercial purposes is another object of the Radio Central installation. Trans-atlantic telephony will, no doubt, be something of a luxury for the immediate future. The radiation intensity needed for telephony is much greater than for telegraphy, and a plant designed purely for telephony might prove very expensive. However, the flexibility of the Radio Central, where any number of antennas can be combined when desired to produce a more efficient radiation, will make an extra powerful transmitter available when needed, while the plant may be used in a more economical way at other times for telegraphy.

SUMMARY: There are considered the mechanism of radiation and reception in radio communication. The design of the transmitting equipment is compared with the design of the usual alternators and power plants of electrical engineering. The main problems encountered are described, and an account is given of the solutions obtained. The development of the Radio Central Station for telegraphy and telephony is discussed, its arrangements described, and its usefulness indicated.

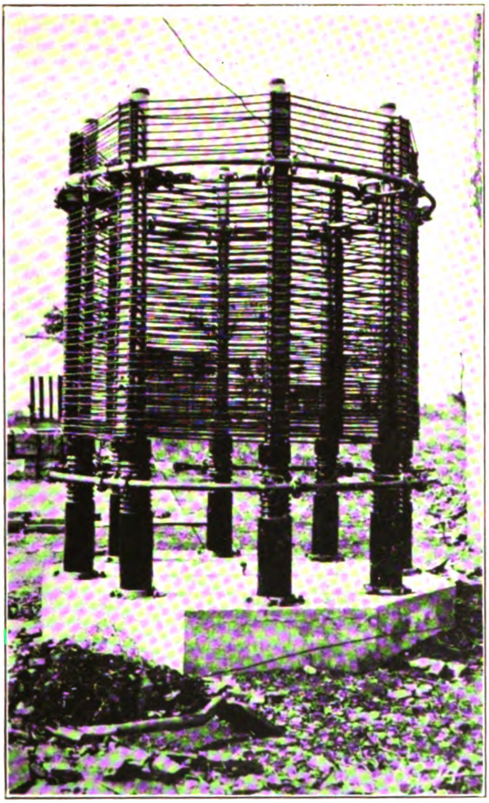

FIGURE 1—One of the Outdoor Loading Coils Used on the Multiple Tuned Antenna

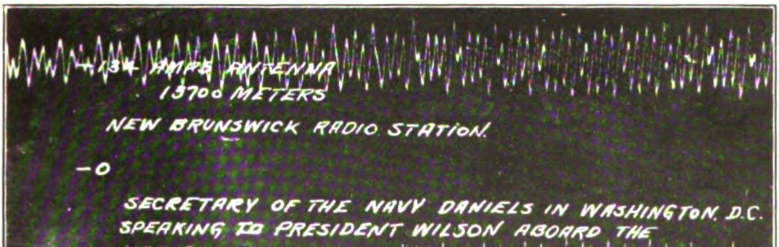

FIGURE 2—Secretary of the Navy Daniels in Washington, D.C., Speaking to President Wilson Aboard the U.S.S. *George Washington*

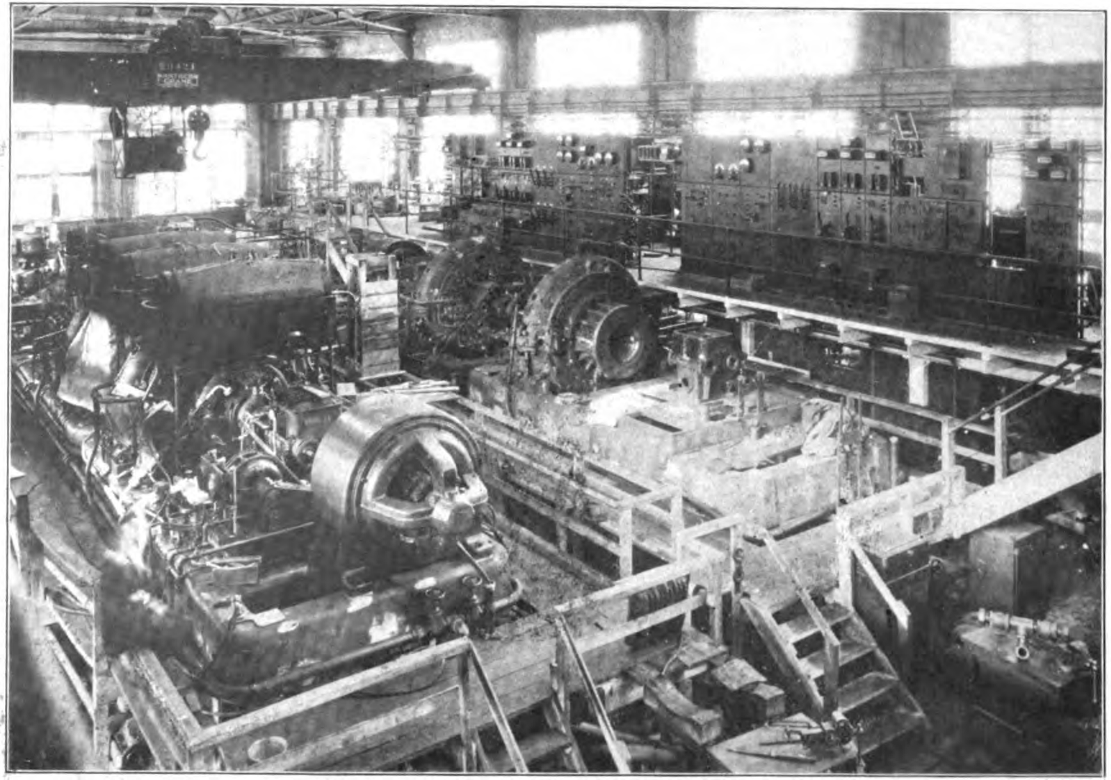

FIGURE 3—Section of the Building Where Radio Power Plants Are Being Manufactured at the Rate of Two Per Month

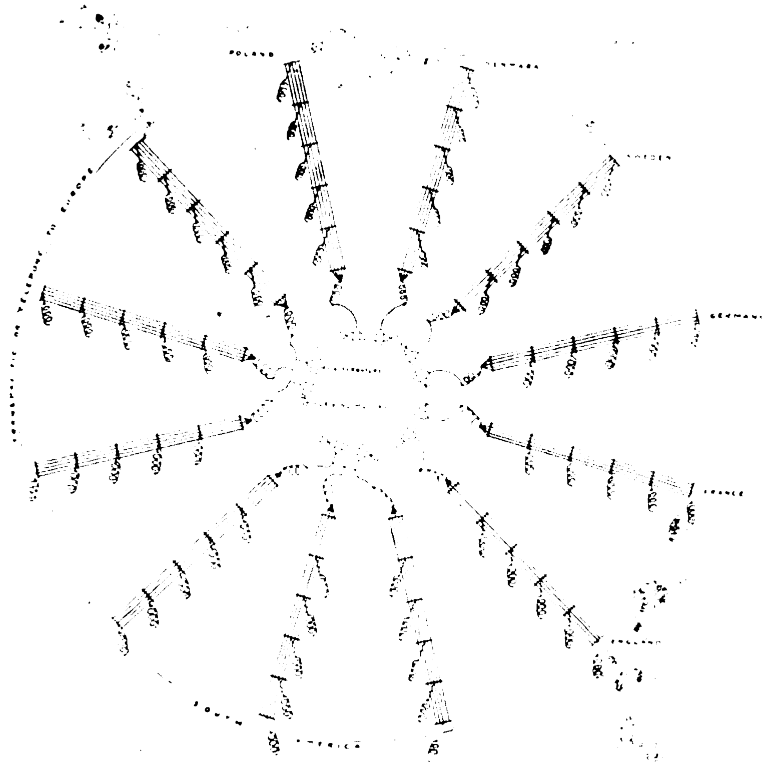

Figure 4—Antenna Combinations for the New York Radio Central Station

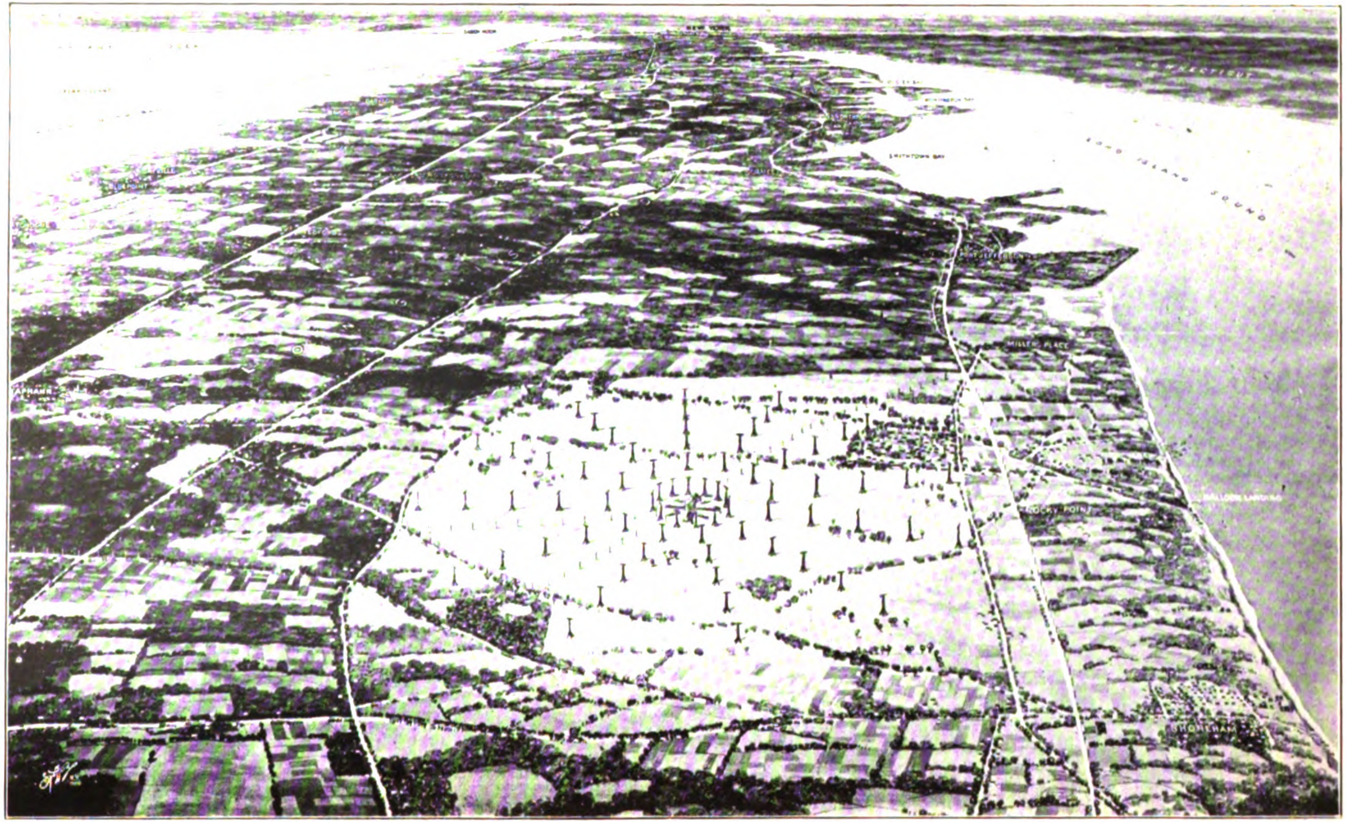

FIGURE 6—New York Radio Central Station

THE SPECIFICATIONS AND CHARACTERISTICS OF MOORHEAD VACUUM VALVES*

By

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and

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The war has been responsible for some remarkable developments in radio apparatus, among which the vacuum valves have played an important part. The varied uses to which valves have been applied has necessitated the manufacture of large quantities of valves having uniformity of operating characteristics.

The British Government required a considerable number of vacuum valves, and while they were being built by hand in England, the supply was not sufficient. The valve adopted by the British Government was presumably copied from the French type, and complete specifications were submitted by the British Government which cover a large amount of detail. The writers will discuss part of these specifications in the following, calling attention to the careful mechanical measurements contained therein.

The Type "R," which is the British receiving tube, is of the three electrode type. The anode consists of a rectangular sheet of pure nickel 31 mm. × 15.2 mm. (1.22 × 0.6 inch), rolled into a cylinder 10 mm. (0.39 inch) external diameter, the thickness of the metal being 0.2 mm. (0.08 inch). The grid consists of a nickel wire 0.25 mm. (0.10 inch) diameter and 165 mm. (6.5 inches) long. This wire is bent into a spiral of 11 turns. The pitch of this spiral being 1.5 mm. (0.06 inch), the internal diameter is 4.25 mm. (0.17 inch). The filament is pure drawn tungsten wire, diameter 0.061 mm. (0.0024 inch) and 23 mm. (0.91 inch) in length when uncrimped.

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*Delivered before the San Francisco Section of The Institute of Radio Engineers, November 14, 1919. Received by the Editor, December 8, 1919.

The disposition of the electrodes is made as follows: The grid spiral and anode cylinder are placed so their axes are coincident with the filament. The grid is set so that 9 of its turns are within the cylinder and one turn projects at each end of the anode.

The size of the glass bulb specified is not to exceed 54.76 mm. (2.15 inches) external diameter, and the length from the remote end of the pins on the base to the tip 111.91 mm. (4.41 inches).

The British and French type of base is used, but was improved upon considerably by base manufacturers in this country. An unusual degree of mechanical accuracy was required in the base and terminal pins, a few figures for which are given here. The diameter of the terminal pin is 3.171 mm. (0.125 inch) and a tolerance of but 0.075 mm. (0.003 inch) is allowed. The length of the pin projecting from the base is 17.462 mm. (0.688 inch). Numerous test gauges are used in checking the assembled base and valve.

The electrical tests specified are characteristic of the mechanical details as contained in the specifications. To test the correctness of the disposition and proper dimensions of the elements, the filament is supplied with four volts, the anode being maintained at 80 volts positive with respect to the negative end of the filament, and a curve obtained by plotting as abscissas the potential difference of the grid in respect to the negative end of the filament and as ordinates the filament plate current. This curve must be a straight line for variations of grid potential between (minus three) and (plus twenty-five) volts, a variation of 1 volt grid potential producing a variation of plate current of at least 0.2 milliamperes. Furthermore, when the grid and plate are connected together and a potential of eighty volts applied to them, the current then obtained between the filament and these two electrodes must be above 8 milliamperes.

The bulb must be so evacuated that the "backlash" is between 0.5 and 0.02 microamperes. The method of obtaining the backlash is described here. A potential is applied to the grid, the anode being at 160 volts positive, and filament voltage 4. A curve is plotted, taking the grid current as ordinates and the negative grid voltage as abscissas. The negative current represented by the ordinate when the grid potential is 2 volts negative in respect to the filament, is the backlash. Further testing when the grid potential is removed, all other conditions the same, the positive current to the grid must not exceed 1.5 microamperes.

The electrodes and all internal parts of the valve must be so freed from gases that no deterioration of the vacuum occurs when the anode is dissipating 15 watts energy for three minutes continuously. The anode dissipation is measured in the following way: The filament is supplied with 6 volts, the anode with 400 volts, and the grid with positive potential until the plate current reads 37.5 milliamperes. During the continuance of this test, no blue glow must appear in the bulb.

The filament current when six volts are applied must be 0.84 ampere with a tolerance of 0.035 ampere. The contact of the leading-in wires with the elements must be such that, when the valve is used in a 4-stage amplifier, no crackling sounds are heard. The insulation of the base must exceed 150 megohms when the valve is not lighted. The valve has a life of 800 hours when four volts are used on the filament.

The British Type "B," which is a transmitting valve, will next be considered.

The anode is a rectangular sheet of nickel 31 mm. (1.22 inch) by 16 mm. (0.63 inch), rolled into a cylinder of 100 mm. (0.394 inch) external diameter, the thickness of the metal being 0.22 mm. (0.0087 inch). The grid consists of molybdenum wire, diameter 0.2 mm. (0.008 inch) and length 330 mm. (1.3 inch). This wire is bent into a spiral of 22 turns, the pitch being 0.75 mm. (0.040 inch), the internal diameter being 4.1 mm. (0.16 inch). The filament is drawn tungsten containing a small percentage of thorium, the diameter of this wire being 0.058 mm. (0.0023 inch) and the length 22 mm. (0.87 inch).

The valve is assembled like the Type "R," and the following electrical tests applied: disposition of electrodes, and correctness of dimensions. The anode is maintained at 600 volts positive; six volts are applied to the filament; the grid is maintained at the same voltage as the negative end of the filament. Then the plate current must be 17 milliamperes plus or minus 6 milliamperes. The grid is next supplied with 10 volts positive, and the plate current must exceed by 5.5 milliamperes that current observed in the previous case.

The vacuum is tested as in the type R case except that the anode must dissipate 50 milliamperes at 600 volts for three minutes continuously. During this test the anode becomes white hot. No backlash test is made, but the filament emission is measured by connecting the grid and plate together and applying 80 volts with respect to the negative end of the filament, which is supplied with 4 volts. The current thru the valve must then exceed 5 milliamperes.

The filament current when 6 volts are applied must be 0.85 ampere with a tolerance of 0.04 ampere.

The valves were constructed of materials produced in the United States, and the specifications followed carefully. When the completed valves were tested, they agreed with all the electrical measurements described above.

The type R valve, however, had its elements mounted vertically. This was done as the specifications did not cover the position of the elements, and no samples were available in this country at that time. Samples did arrive, however, before the type B was made, and the elements were changed to a horizontal position to conform to the French sample.

The United States Navy type, SE-1444, was the next valve constructed, using the helical grid and cylindrical plate.

A few mechanical changes will be noted, namely, that the grid and plate supporting wires were separated as much as possible, and made of heavier material. The capacity was decreased by these changes, while the internal impedance and amplification constants remained about the same as the British valve.

This type of construction is still used in the valves supplied to the Marconi Wireless Telegraph Company, and known as the "Marconi V. T." However, the flash exhaust is not used in the Marconi V. T., class 2. That is, a vacuum permitting gas action is used in this particular class of valve.

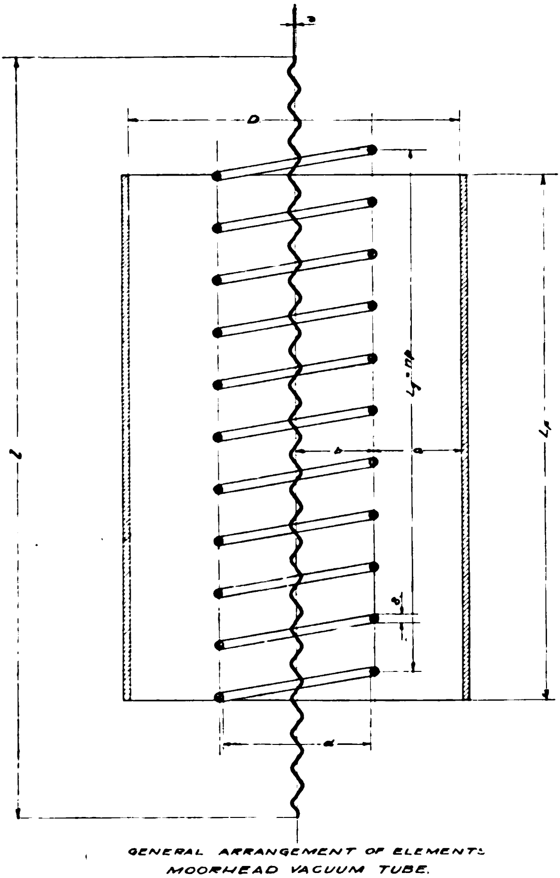
The tendency of the art at this time is to decrease the power consumption of vacuum valves for receiving purposes, and develop a valve which shall consume less than 1 watt, still retaining the high constants of the larger valve. The filaments will be so accurately mounted that no manual adjustment will be required for the proper temperature and emission. The valve will be made much smaller, and a type of base with very low capacity will be used. This will also greatly decrease the cost of the present valve.

THE CHARACTERISTICS OF MOORHEAD VACUUM TUBES

The authors will not dwell on an historical review of vacuum tubes in general, nor will they go into a detailed description of tubes, such as the Fleming valve, kenotron, de Forest audion, pliotron, and so on because most radio engineers are familiar with these. For the same reason, and also because of detailed specifications given in the first part of this paper, further description of the Moorhead tube, or rather Moorhead tubes, will be omitted.

In general, the Moorhead tubes can be divided into two classes: the "soft" tubes and the "hard" tubes. To the first class belong the "Electron Relay" and "Class B," or "Class 1" tubes; to the second class belong the SE-1444, or "Class 2" tube, and the "Type C" tube, also the "British B" and "British R."

The "Key Figure" here given illustrates the general construction of these tubes and their dimensional nomenclature. The "Electron Relay" and the "Class 1" tube (also called "Moorhead Audion") belong to the class of detector tubes depending on the presence of traces of gas for their action. Figure 1 shows the representative characteristic curves of this type of valves.



Key Figure—Construction of Moorhead Tubes and Principal Dimensions

Both the "Electron Relay" and the "Class 1" tubes are identical in their action, there being only a difference in mechanical construction.

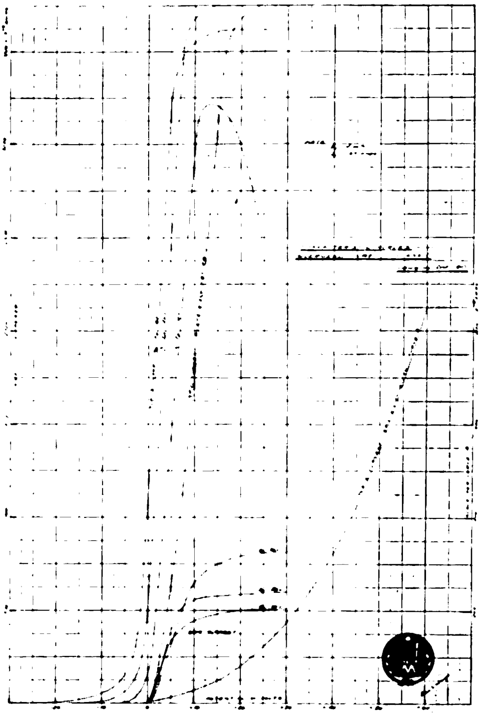


Figure 1

Paralleling the above class of tubes, a type of tube known as "British R" has been developed. This tube has a "hard" vacuum, but the elements are of such proportions as to permit the application of lower plate potentials for the use as a detector tube, this same tube making a comparatively good amplifier when higher plate potential is used. The characteristic curves of this type of tube are shown in Figure 2. These curves show that the plate potential should be between 20 and 40 volts when used as a detector with the grid potential about 2 volts.

Examining the curves of Figure 1, it becomes evident that the tube makes the best detector with about 20 volts plate potential and 0 volts grid potential; the higher plate potentials requiring higher negative potentials of the grid.

Comparing the curves of the two tubes we will find that the "Class 1" tube, or "Moorhead Audion," is a more sensitive detector than the "British R" tube.

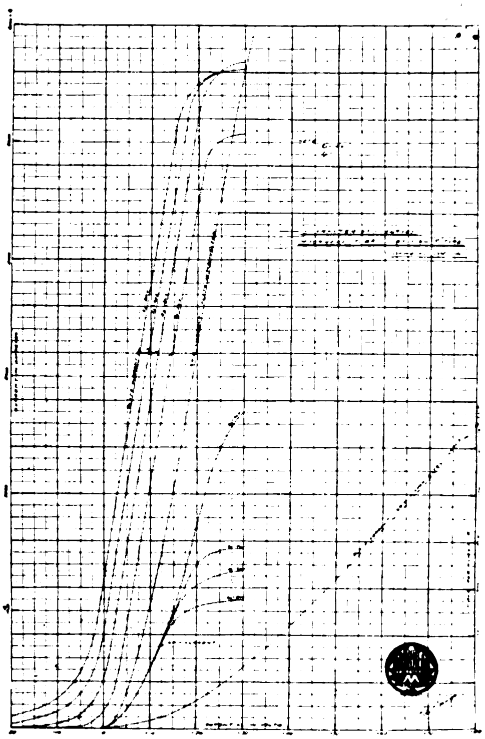


FIGURE 2

In general, as will be demonstrated later, two widely different designs of tubes should be adhered to: one for detector tubes and one for amplifier tubes. While the same tube may serve as detector and amplifier (for example, "British R" tube and SE-1444 tube), yet this is accomplished at a sacrifice of the best operating characteristics. From a number of tubes specially built for the purposes of research, the fact that a tube making the best amplifier makes a poor detector and conversely, has been brought out very clearly.

The authors' research work was undertaken chiefly with the purpose of developing a tube having high amplification and low resistance,—characteristics very much desired. The extent of research work is shown by the accompanying plots of tests of a few of the tubes selected in such a manner as to show the extreme results obtained. The static method in all cases was used, which, altho erratic to some extent, permits calculation of coefficients, or constants, as defined in Mr. Ballantine's paper (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, April, 1919).

Particular attention was paid to the determination of following constants:

$$\mu = \frac{d E_p}{d E_g} = \frac{\text{change of plate potential}}{\text{change of grid potential}} = \text{amplification constant.}$$

(The author suggests the term "grid control coefficient.")

$$R_o = \frac{d E_p}{d I_p} = \frac{\text{change of plate potential}}{\text{change of plate current}} = \text{internal resistance.}$$

$$\rho = \frac{\mu}{R_o} = \frac{d I_p}{d E_g} = \frac{\text{change of plate current}}{\text{change of grid potential}}.$$

All of the three ratios, which are called constants, are by no means constant, their values varying within wide limits for the same tube. The accompanying curves of Figure 3 give the magnitudes of such variations in values of an SE-1444 tube. These variations are by no means accidental, but are inherent characteristics of every tube. Particular attention may be called to

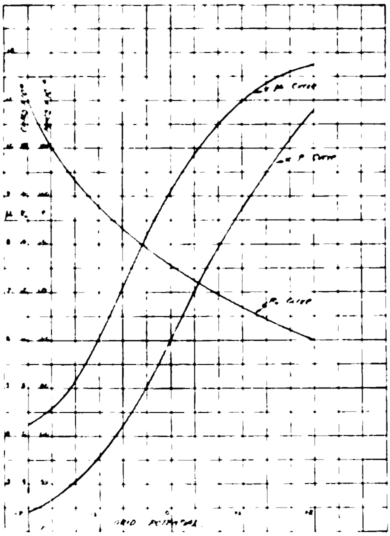


FIGURE 3

behavior of the two of the "constants," the amplification constant and the internal resistance. Every small gain in amplification results in an increase of internal resistance, and it does not seem possible to build a high power amplifying tube of low resistance.

Moreover, the same types of tubes, made in exactly the same way, with the same precautions during the process of manufacture, of the same materials, in short, tubes supposed to be identical in every respect, show variations with regard to the operating characteristics, in addition to the variations mentioned above. The magnitude of these variations is clearly shown in Figure 4.

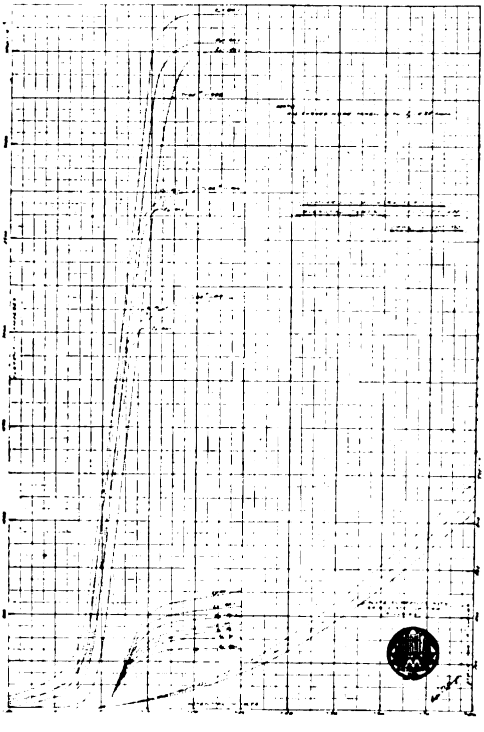


FIGURE 4

The three sets of characteristic curves plotted to the same scale very vividly show how minute defects, detection of which under ordinary conditions and with less sensitive apparatus would be termed "hair splitting," will change the characteristics of a tube.

The plate material strained a little while being rolled into the cylindrical shape and slightly opening when subjected to high temperature, will get away a fraction of a millimeter from the grid; the result is that the characteristic of the tube can hardly be recognized; slight variations of tension on the filament wire, uncertainty of supports retaining their shape when brought up to a temperature of about 800 degrees Fahrenheit (426° C.) during the exhaustion, or to a still higher temperature during the "blue-glow" process,—all these causes will have their effect. In addition, there are gases in the metal of tube elements, which gases, tho driven out of metal at very high temperature, defy the action of the "getter" and are re-absorbed by the metal to be driven out again when the tube is allowed to reach a high enough temperature—and we all know what a trace of a gas will do to the characteristic of tube. The result is that, to be exact, there is one chance in a thousand to get two tubes that will be absolutely alike. But this *is* "hair splitting." Thousands and thousands of tubes have been built and have given absolutely satisfactory service by slight variations of minor accessories of the circuits using a tube. On the whole, and for all practical purposes, the hard vacuum tube shows a consistent uniformity. A tube of definite design will give definite results within very close limits.

At this point, we shall temporarily abandon the discussion of general characteristics and consider the characteristics shown by each of the tubes tested by the authors, including even the soft tubes.

Up to the present date, as has been stated by an authority, quoted literally, "the vacuum tube art is in a very fluid state." The action of the tube in general has been studied and the tube has been made use of for several very different applications, all, more or less, successful. But in spite of wide applications of the tube, in spite of its being in use daily all over the world, no satisfactory solution of a mathematical theory has been given. The fact that all of the tubes (speaking of the three element tubes) have similar characteristics, their characteristic curves showing that they all belong to the same family, leads to the belief that one and the same law of action governs them all. Mathematical formulas have been advanced, but these formulas as tested by the authors, did not give satisfactory results. It is only to be hoped that more research work and more detailed study will be done in connection with the tube to arrive at the law determining the action of the tube, no matter what its shape, and no matter what its proportions may be.

In what follows, the authors will not try to advance any mathematical theory, but will confine themselves to presenting a few observations of the action of the tube elements, which actions being absolutely uniform may lead to a founding of a definite theory of the vacuum tube.

The first element to be mentioned is the tungsten filament. Taking measurements on different sizes of filament wire, both straight and crimped, the authors have found that the specific resistance of material of the filament was 0.000,005,58 ohms, or 5.58×10^{-6} ohms per cm.^{3}, which result corresponds very closely with that given by the Bureau of Standards, which is given as 5.6×10^{-6} ohms. The temperature coefficient was taken from the same source and used as an average of 0.0045 per degree Centigrade. It was found that the crimping added 27 to 30 per cent to the resistance, thus increasing the length of the filament wire about 30 per cent. Using a specific resistance $\rho = 5.6 \times 10^{-6}$ ohms, the curve of resistance of tungsten wire of different diameters has been calculated and is given in Figure 5.

All of the tubes used in the tests, except the "British B" tube, have 0.061 mm. (0.0024 inch) diameter filament wire 23 mm. (0.905 inch) between the supports. The average filament resistance is 0.565 ohm at about 20 degrees Centigrade; at this

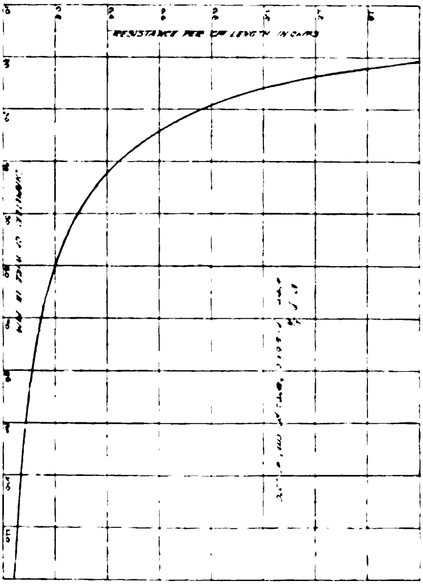


FIGURE 5

temperature the combined resistance of copper wire connections, platinum seals, and nickel supports measured 0.08 ohm. Figure 6 gives resistance, temperature and current curves of 0.061 mm. (0.00241 inch) and 0.058 mm. (0.00228 inch) diameter filaments. The temperature and resistance curves are those of 23 mm. (0.905 inch) long, 0.061 mm. (0.00241 inch) diameter filament. For practically all of the tests the filament voltage was kept at 4 volts.

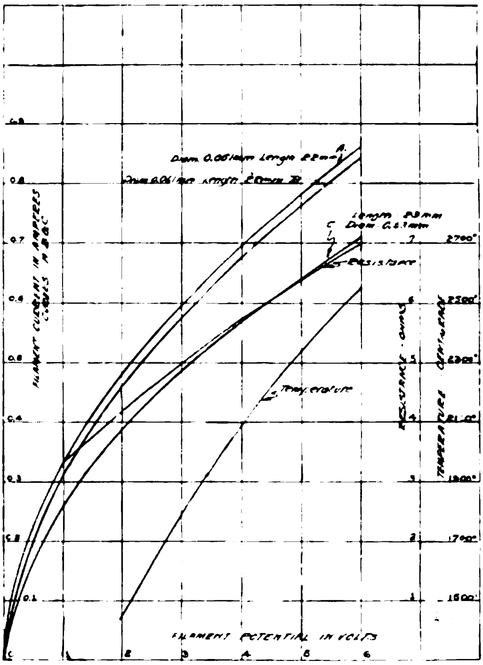


FIGURE 6

From Figure 6 it will be seen that the filament was at about 2, 100 degrees C. when using 4 volts, and that its temperature is raised to about 2,600 degrees C. using 6 volts. It was the authors' intention to give an account of every test at 4, 5, and 6 volts on the filament, but such comparative tests will be reserved for the future.

The electronic mission has been carefully studied by Richardson, who expressed the law governing the emission of electrons in an equation analogous to the equation of evaporation of liquids. This equation appears below, together with sample calculations of the current. The two constants entering into the equation were taken as calculated for tungsten by Langmuir.

The length of the filament being 23 mm. (0.905 inch) between the supports, or about $23 \times 1.3 = 29.9$ mm. (1.18 inch) effective, we have for the exposed area of filament

$$A = \pi d l = 3.146 \times 0.0061 \times 2.99 = 0.057 \text{ cm.}^2 \text{ (0.00086 sq. in.)}$$

Figure 7 shows a graph of the "thermionic" equation given by Richardson which is

$$i = A T^{\frac{1}{2}} \varepsilon^{-\frac{b}{T}}, \qquad (1)$$

where T = temperature of filament (Kelvin or absolute)

$$a = 23.6 \times 10^9$$

$$b = 52.5 \times 10^3$$

or

$$i = 23.6 \times 10^9 \, T^{\frac{1}{2}} \varepsilon^{-\frac{52500}{T}} \text{ milliamperes/cm.}^2$$

Calculated emission at 2,100 degrees C.,

$$i = 14.95 \times 10^{-3} = 853 \times 10^{-6} \text{ amps.}$$

The above results represent the maximum electronic emission available at the surface of the filament as the equation is strictly "thermionic" and does not take into consideration the presence of a charged body or the separating space between same.

On the other hand, we have an equation giving the maximum current in the cylinder with the wire filament at the axis of the same.

$$i_{max} = 14.65 \times 10^{-6} \frac{V^{\frac{3}{2}}}{r} \text{ amps./cm. length of the cylinder} \qquad (2)$$

V = applied potential

r = radius of the cylinder.

Calculating the current which would flow in a tube having 10 mm. (0.394 inch) diameter plate and 15.2 mm. (0.6 inch) long, we would have for 10 volts potential of the plate

$$i_{max} = 14.65 \times 10^{-6} \times 1.52 < \frac{\sqrt{1000}}{0.5} = 14.1 \, (10)^{-4} \text{ amps.}$$

This equation does not take into account the temperature of the filament, which is not quite correct, as the temperature of the filament has an effect on electronic emission,

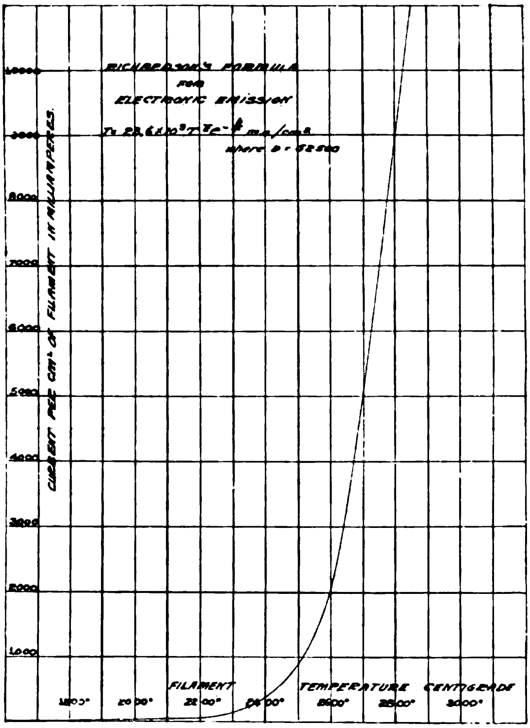


FIGURE 7

more noticeable as the potential increases. Figure 8 shows the plate potential curves of two hard vacuum tubes without grids at 4 and 5 volts filament potential; two soft tubes without grids were also tested and it will be noted that, up to the potential of 10 volts on the plate, the curves show uniform rise but for the higher potentials on the plate the saturation of the soft tubes becomes very marked. The difference between the 4- and 5-volt curves is very slight, demonstrating that the increase of the temperature of the filament does not materially increase the flow of the current. Carrying out the calculation for 20 volts plate potential, we will have

$$i_{max} = 14.65 \times 10^{-6} \times 1.52 \times \frac{\sqrt{8000}}{0.5} = 39.9\,(10)^{-4} \text{ amps.}$$

The theoretical curves have been plotted in Figure 8. The curve in dashes indicating the position the curve for 5 volts should be corrected as the voltmeter was later found to be reading 1.5 volts too high.

With the above correction, the theoretical and the actual curves are brought close together.

Examining the equation for the current of the tube with cylindrical elements, or

$$i = \frac{2}{9}\left(\frac{2e}{m}\right)^{\frac{1}{2}} \frac{V^{\frac{3}{2}}}{r},$$

we note that the diameter of the filament wire is not taken into consideration at all. The formula makes it appear that the current is altogether independent of the diameter of the filament, which, in the opinion of the authors, is not correct. As will be demonstrated later, the size, or diameter, of the filament is a very important factor in the analysis of the action of the tube and in determining the velocity of emission of the elementary charge. Reference may be had to the curve of forces due to an electric

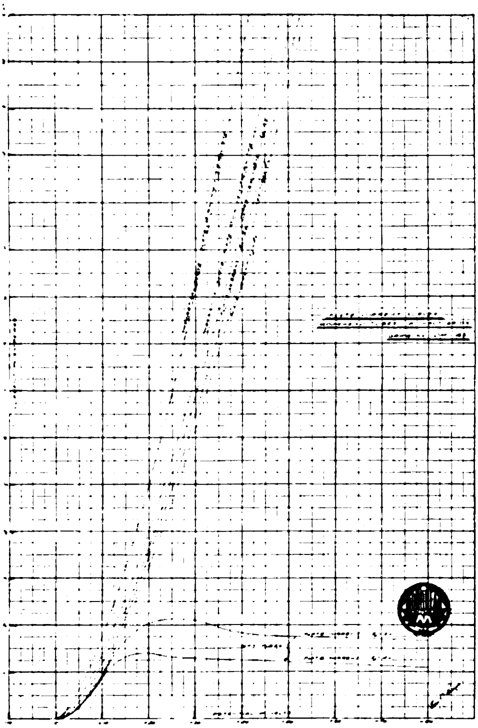


FIGURE 8

charge on a cylindrical conductor such as filament. The formula gives higher results than are obtainable in actual tubes.

Figure 9 gives a series of plate and grid currents, with all elements assembled in place, except one which shows the curve of the plate current of a two-element tube (the same as Figure 8).

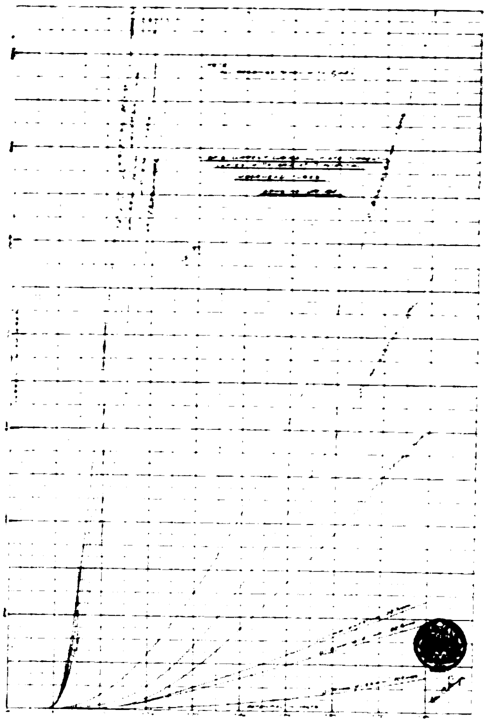


FIGURE 9

Studying the curves we will find that the plate-current curve of the gridless tubes runs together with grid current curves. All other curves represent the plots of readings of plate-filament current, with grid kept at zero potential by grounding it; when taking grid-filament current readings the plate was grounded. (No difference in readings was noted when grid or plate were not grounded). Each curve on this drawing very closely follows the equation

$$Y = A X^{\frac{3}{2}}$$

This equation appears to express the law governing the operation of any two-element valve, within the limits of saturation, The saturation point of the valve depends on the filament temperature and the potential difference between the filament and the anode. The difference between the results as given by the "thermionic" equation (1), and equation (2), is evidently due to acceleration of emission due to applied potential. This may also explain the difference between the slopes of the calculated curves and those plotted from actual tests.

It will be noted that checking the curves from point to point, the rise of the curves is not exactly in the ratio of $\frac{V_2^{\frac{3}{2}}}{V_1^{\frac{3}{2}}}$, but is more correctly in ratio of $\frac{V_2^{\frac{3}{2}}}{V_1^{\frac{3}{2}}}k$, where $k < 1$, and may be taken as a factor giving the difference of total potential applied minus the potential required to force the emission of electrons in excess of natural emission, or emission which would take place if the filament were removed from the influence of a charged body.

Figure 10 gives the plots of tests of the grid-filament current characteristics. The sketches of Figures 11 to 14 inclusive show the same curves to the smaller scale. From the curves, it is evident that the same law of the flow of current applies in this case also. Three different sizes of grids were tested, in each case the plate was grounded and thus kept at zero potential.

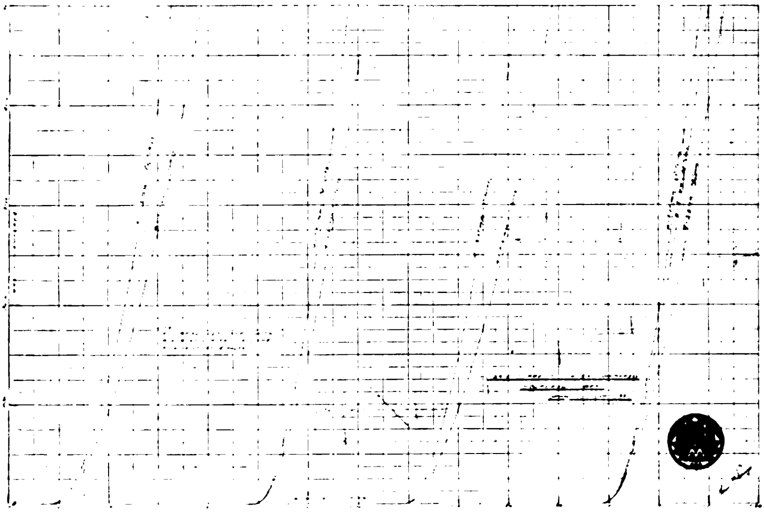
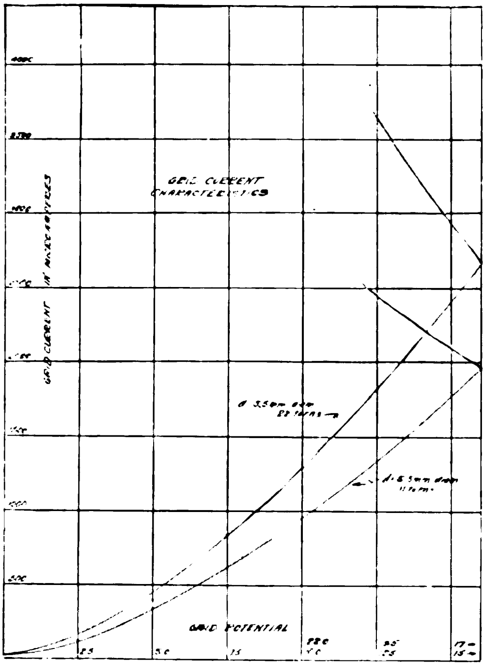


FIGURE 10

Figures 11 thru 14 represent the grid potential-grid current curves. The tests were taken with grids 11 and 22 complete turns, 3.37, 4.1, and 5.5 mm. (0.133, 0.162, and 0.217 inch) diameters respectively (these diameters are the diameter of mandrels used in the winding of the grids and, therefore, represent the inside diameter of the grid spiral). The wire used was 0.010″ = 0.254 mm. diameter The pitch of winding for the 11-turn grid was 1.5 mm. (0.059 inch), that for 22-turn grid was 0.75 mm. (0.0295 inch).

Figure 15 gives grid potential-grid current characteristic of a tube having grid and filament only. The same drawing shows three computed curves for plates of length equal to the length of grids and of the same internal diameter. It will be noted that the ratio of values of plate current to that of the grid of the same diameter and length, depends on the number of turns of the grid and its distance from the filament.

Figures 11 and 12 (Curves 1 and 2 in Figures 13) show two sets of grid current curves; Figure 7 shows curves for 5.5 mm. (0.217 inch) inside diameter grid, Figure 11 for 3.37 mm. (0.133 inch)



FIGURES 11

diameter grid. These two sets of curves give the variation of current as a function of number of turns, and show that by doubling the number of turns of the grid we do not double the current. The difference between the values of current for the same size of grid but different number of turns appears to be not only a function

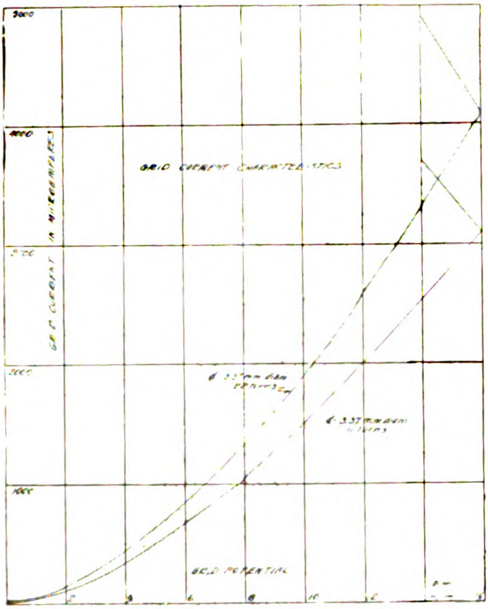


FIGURE 12

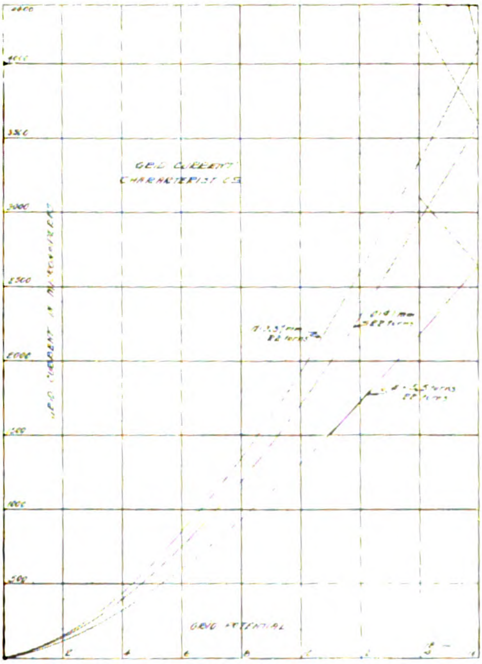


FIGURE 13

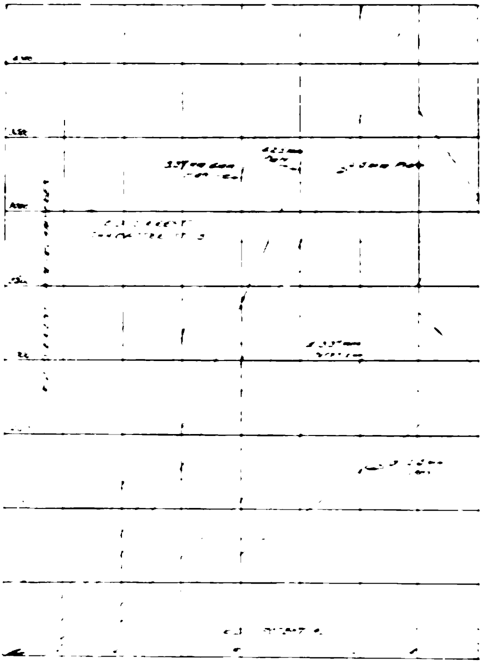


FIGURE 14

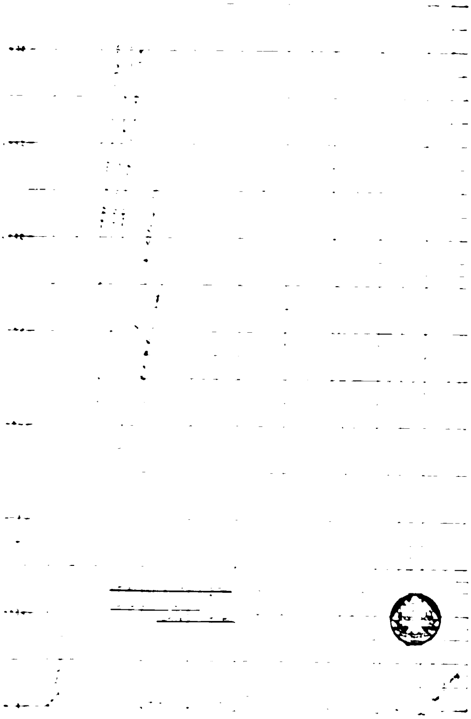


FIGURE 15

of the number of turns but also a function of its distance from the filament and the potential applied. The determination of this function, we believe, will completely solve the problem of mathematical predetermination of characteristics. Two curves in Figure 16 show the variation of current difference with varied potential for 11- and 22- turn grids, and it will be noted that the slope of the curve 3.37 mm. (0.133 inch) grid is considerably greater than that of 5.5 mm. (0.217 inch) grids. The variation of grid current as a function of the diameter turns is clearly shown in Figure 13, representing the current curves for 3.37, 4.1, and 5.5. mm. (0.133, 0.162, and 0.217 inch) diameter grids. The curves show a certain consistency, but do not follow exactly the ratios of their diameters.

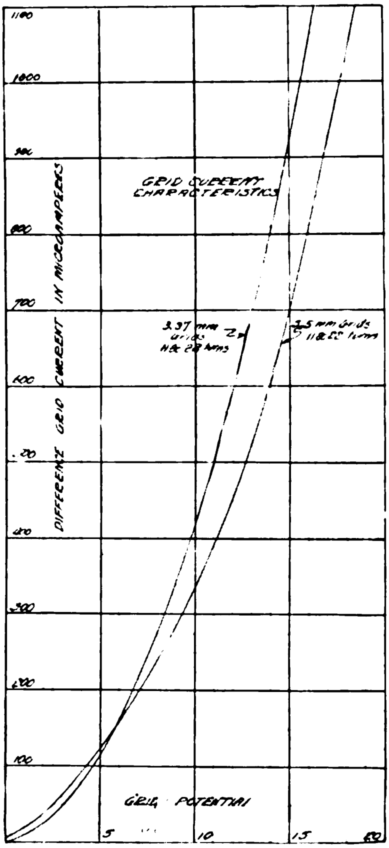


FIGURE 16

Figure 17 gives the curves of grid current differences as function of diameters of the grid and the potential applied. Here the curve for 22-turn grid shows a greater slope than that of 11-turn grid. It is impossible for the authors to present at present

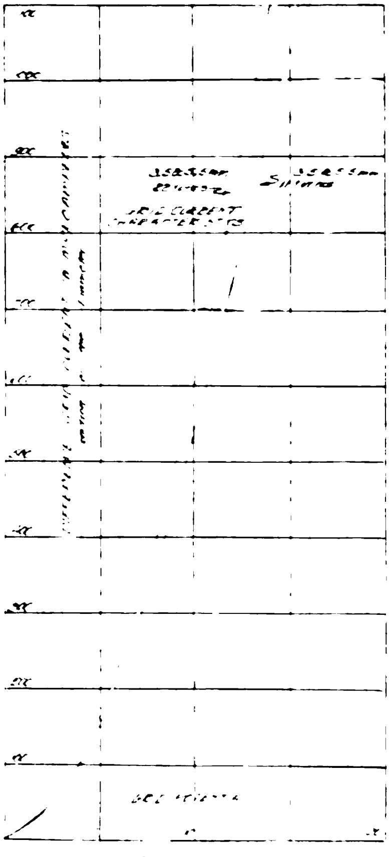


FIGURE 17

a complete analysis of grid action, as the observations and experiments are not complete. Several special tubes will have to be made and carefully tested before conclusive interpretation of the grid action may be given.

It is the writers' opinion that the action of the grid is dependent upon the distribution of the charge on the grid; due to its non-uniform distribution, the path taken by the elementary charge diverges from a straight line, as it would if no charged body were present near the filament. The grid consisting actually of a number of rings will produce a field as indicated on the attached force diagrams, Figures, 18, 19, and 20. These force

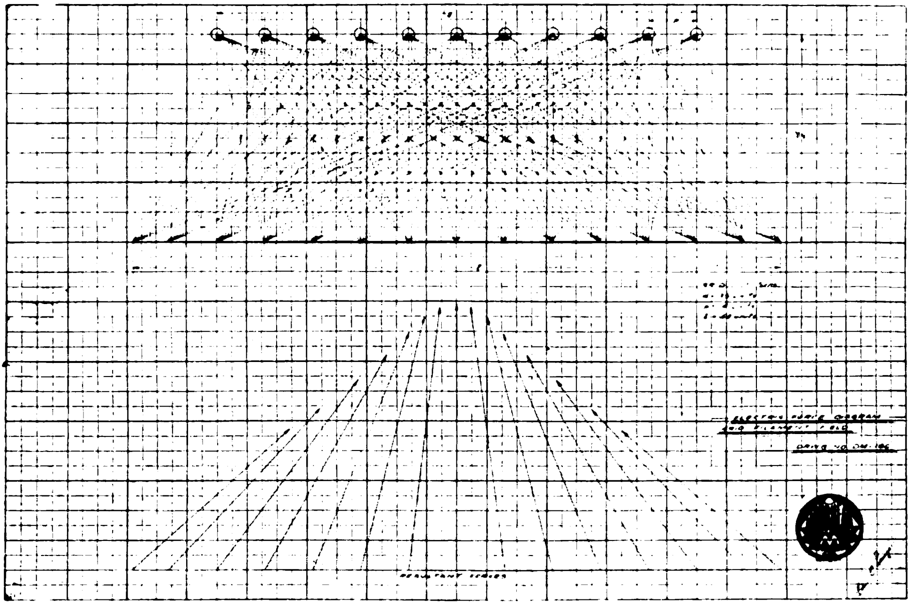


FIGURE 18

diagrams indicate that the moving charge, purely under the action of grid, without the action of any body placed outside the grid, will be crowded toward the center turns of the grid, this action becoming more and more apparent as the diameter of the grid decreases. The diagrams were drawn for arbitrarily assumed values for the diameter, spacing, and so on, with the sole intention of studying the resultant action of a number of rings, or turns, placed concentrically with regard to the filament. The curves on Figure 21 represent the values of forces from point to point extending thru the whole length of the filament; the values of the resultant forces were taken disregarding their direction, for 1, 3, 5, and so on turns of the grid. The curves are self-explanatory and show very clearly that with increasing number of turns and increasing diameter of the grid, its action on the filament (or, rather, its action in the space between fila-

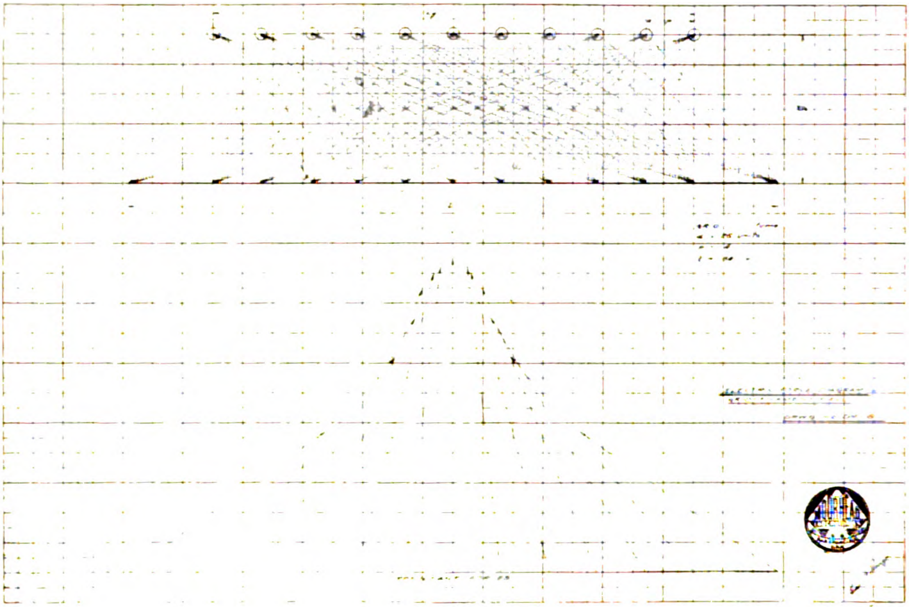


FIGURE 19

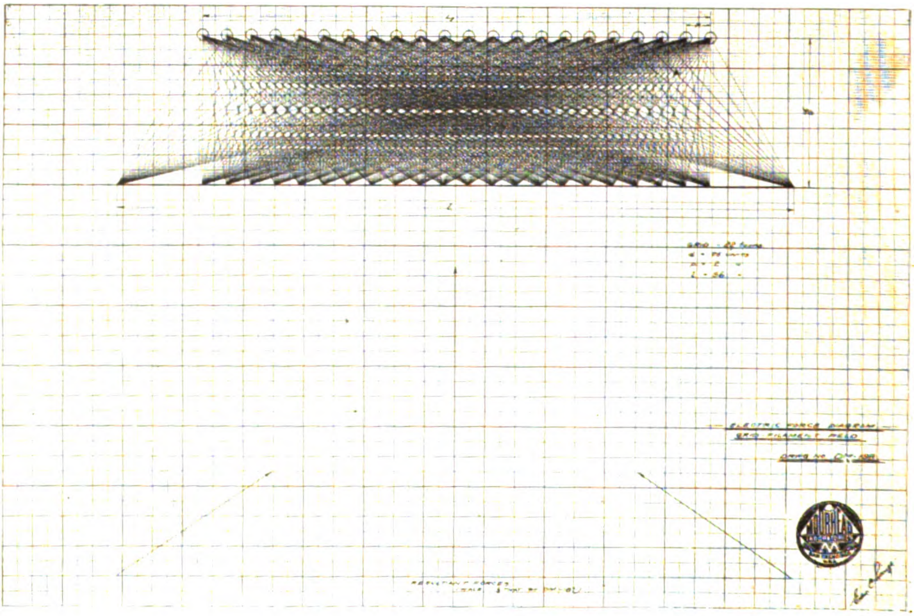


FIGURE 20

ment and grid) becomes more and more uniform. In general, the number of turns, their spacing, and the diameter of the grid and also length of the filament and its diameter, all have to be considered in an analysis of grid characteristics.

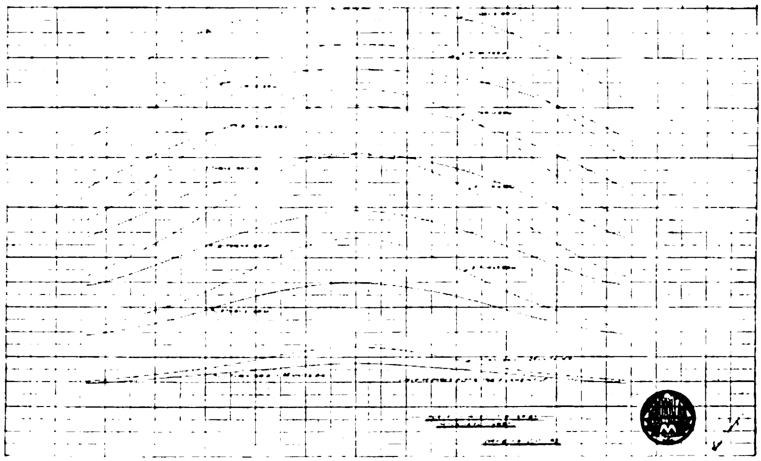


FIGURE 21

The equation (2), according to the above statement, can not be applied in the case of grid. Studying the characteristics of two-element tubes consisting of the filament and plate only (so-called gridless tubes,) it was observed that in each case the value of current as given by the formula was too high. This fact is very clearly shown by the curves of Figures 8 and 22, and Figure 8 gives comparisons of the plate-filament current of a hard vacuum tube with that of a soft tube at different temperatures of the filament, and also calculated curves for 8 and 10 mm. (0.315 and 0.394 inch) diameter plates. Figure 22 shows tests of 3 tubes with plates 8 mm. (0.315 inch) diameter. (It must be noted that the specified diameter of 8 mm. is not correct by a wide margin for these tubes; the plates were formed by means of a pair of pliers and then very poorly. The curves are shown solely for the purpose of demonstrating how small mechanical defects will alter the characteristics of a tube). All of the three tubes were exhausted at the same time and with the same precaution, yet they show considerable variation as regards the limits of saturation, indicating some condition practically beyond control.

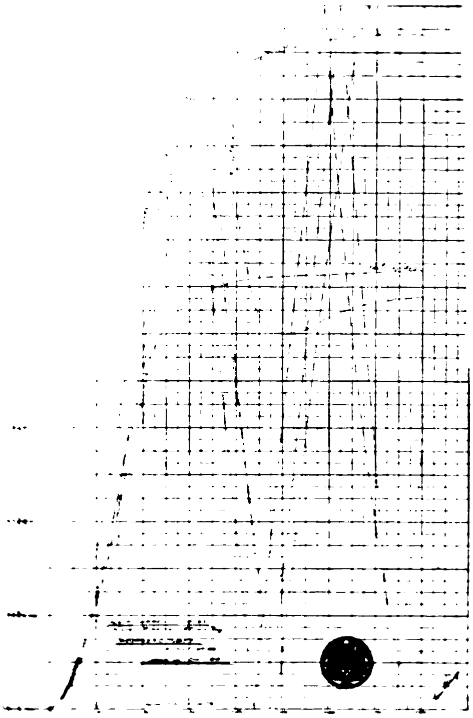


FIGURE 22

In general, it may be said that the plate-filament current at a given temperature of the filament in a two-element tube, consisting of a cylindrical plate and a filament, is a function of the plate diameter, and the diameter of the filament and its length.

Figures 23 thru 27 give the curves representing the values of plate-filament current of hard vacuum tubes, all tubes having the three elements completely assembled in accordance with standard practice. The readings were taken with the grid entirely disconnected grounding of the grid did not affect the readings at all. Thus the action of the grid was confined to a purely screening action and the results obtained were rather startling. The tubes tested had diameters of the plates varying from 8 mm. to 10 mm., 0.315 to 0.395 inch and three sizes of grids were used, 3.87 mm., 4.1, and 5.5 mm. 0.152 0.162 and 0.217 inch and varying the number of turns from 11 to 22. Due to lack of time, no values were tested with grid turns between 11 and 22, but it is expected to complete the tests before final mathematical analysis is completed. The determination of exact relations between the geometrical dimensions of the grid and its action on the plate is more difficult than may appear at first, but, in the opinion of the authors, a few more tests will definitely indicate the laws governing said action. Figure 9

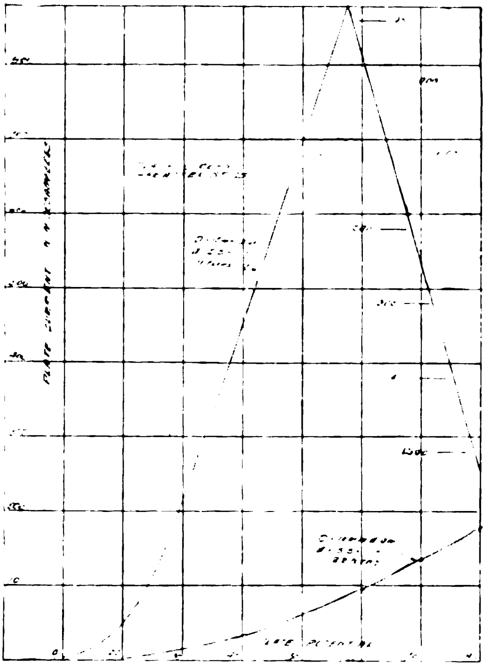


FIGURE 23

shows the plate-filament and the grid-filament current curves; the plate-filament curves were taken with grid disconnected, and are the same as shown on sketches, Figures 23 thru 27, and are plotted here to the same scale in order to bring out more clearly the action of the grid as a screen; the grid-filament current curves were plotted on the same sheet to demonstrate that one and the same law governs the flow of the current for both plate and grid. It is of interest to note that the plate-filament curve of a gridless tube (D = 10 mm. or 0.394 inch) takes its place in this family of curves among the current curves for grids.

A careful study of the curves will reveal several interesting points. Examining the grid-filament current curves, we note that for the same diameter and the same overall length of grid, the current will be greater the greater the number of turns. The difference in current between two grids of same diameter but of different number of turns seem to be a function of the number of turns only, and is independent of the diameter of the grid. As expected, the larger the diameter of the grid, the smaller the current.

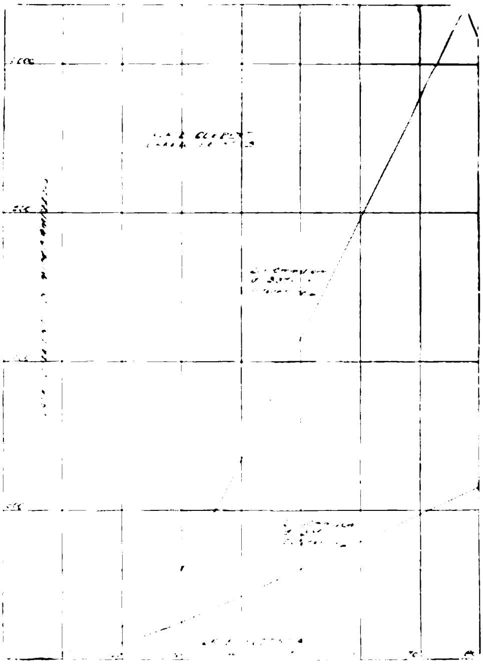


FIGURE 24

We will now compare the plate-filament current curves screened by the grid (grid at zero potential) in greater detail and refer to Figures 23 thru 27. Figure 23 represents current curves of a tube having 10 mm. (0.394 inch) diameter by 15.2 mm. (0.6 inch) long plate (D = 10 mm). The diameter (inside diameter) of the grid is $d = 5.5$ mm. (0.217 inch), the pitch of winding for 11-turns grid being 1.5 mm. (0.059 inch), and that for 22-turns grid 0.75 mm. (0.029 inch). These curves show that a slight difference in values at lower potentials of the plate increases very rapidly as the potential increases, the difference varying approximately as the cube of the potential. The same approximate relation is brought out by the curves of Figure 24, which curves were compiled from readings of tubes of same dimensions as those of Figure 17 except that the diameter of the grid was made 3.37 mm. (0.133 inch). Both of the above sets of curves show the plate-filament current, with grid interposed, but at zero potential, as a function of the number of turns in the grid, when overall dimension of the grid and its relative position with respect to other elements were kept the same.

FIGURE 25

To compare now the difference of the flow of plate-filament current, keeping the number of turns of the grid the same but varying its diameter, the curves of Figures 25 and 26 were plotted. The rate of variation of the current as a function of the diameter in this case is not as apparent as in the above case, but no doubt careful investigations and a detailed analysis will permit arriving at the establishing of relations between the flow of the current and the diameter of the grid.

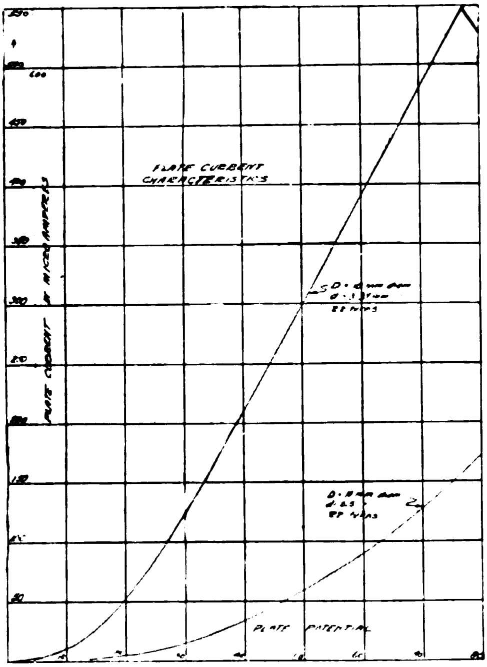


FIGURE 26

Figure 27 shows two curves of tubes having grids and filaments alike in every respect (as near as is possible in their manufacture), but the plate diameters were 8 mm. and 10 mm. (0.316 and 0.394 inch) approximately. In other words, these curves furnish us with information as regards the changes of current as a function of grid-plate distance. With regard to this grid-plate distance, we can state that it appears to have a great influence on the operating characteristics of a tube. As we shall see later, it is this distance that governs the quality of a tube as an amplifier.

We can now take up the study of simultaneous action of all of the three elements of a vacuum tube. Three sets of curves in Figure 4 illustrate completely why it is imperative to duplicate almost all of the foregoing tests. It will be noted from the curves that the three tubes, which, by the way, were taken at random from a large lot, show widely different characteristics. As stated at the very beginning of this article, the causes for such variations are many, and to determine conclusively such causes for the purpose of their elimination, if this be within possibility, it is necessary to carry out series of tests with as many possible variations of dimensions of elements as will be necessary to complete the mathematical analysis. With the aid of such an analysis the various causes tending to distort the characteristics of a tube could be studied with more precision, as could also the possibilities of determining the best which can be expected of a tube.

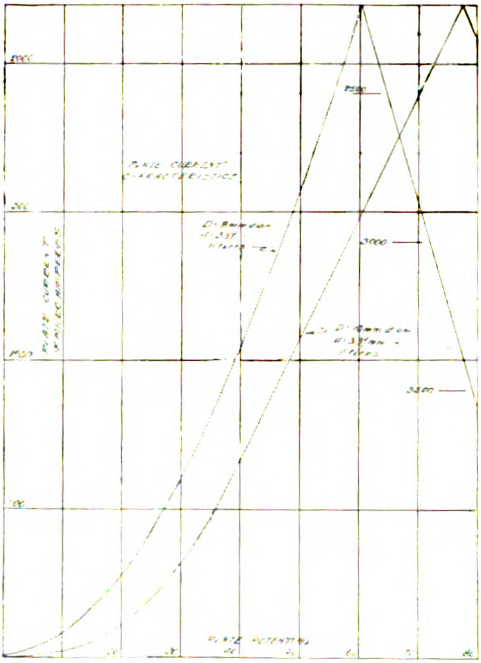


FIGURE 27

Figure 28 shows a complete set of curves of a tube, which by reason of its constancy in action, its characteristics as medium plate-potential amplifier, may be considered a representative type of the vacuum tube. This tube was built for transmitting and amplifying purposes only, and as such has given excellent results. It is the "British B" tube, or Moorhead Type C. These excellent amplifying characteristics were secured by using a 22-turn grid. Comparing with that tube the tube known as "British R" and its duplicate the "SE-1444," we find that by changing the grid from 22 turns to 11 turns, keeping the other elements of the same size, we get a tube which is a fair amplifier and also a fair detector. The characteristic curves of this type tube are given in Figure 2. The tests of the above tubes, together with series of tests carried out on tubes of various dimensions, bring out the fact that to secure best results in the action of a tube as amplifier a certain location of the grid is required, but that, at the same time, this location of the grid is very unfavorable for detector action.

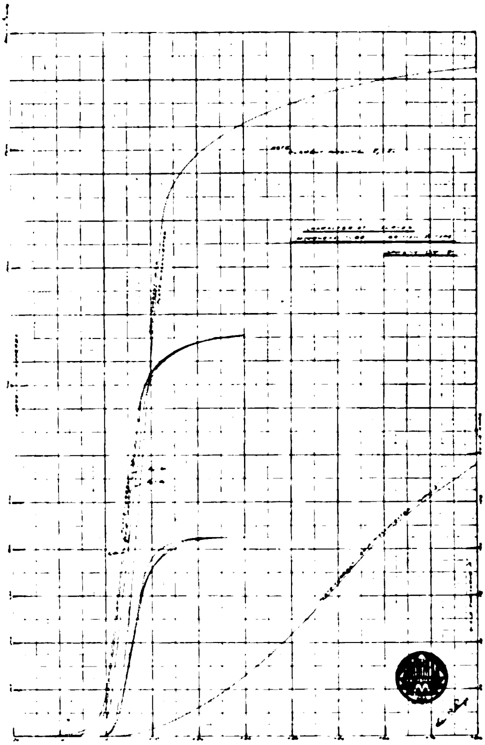


FIGURE 28

The question arises, which conditions must be fulfilled to produce a good detector, and which disposition of elements of the tube is necessary to make the tube a good amplifier. The requirements of a tube as a detector are low internal resistance and that this resistance shall change suddenly, that is, within very narrow limits of grid potential variation. The amplification characteristic of a tube depending on the ratio of the change in plate potential to the corresponding change in grid potential, the maximum action will be obtained when for a given change of the grid potential the increase in plate potential required to maintain the same current will be a maximum.

Thus we find that in a detector the resistance must drop suddenly, for a small change in grid potential, from a maximum to a minimum; whereas in an amplifier a small change in grid potential should tend to increase the resistance to a maximum. This represents the fundamental difference between the two classes of tubes, and conclusively confirms the statement made by the authors at the beginning of this paper.

Figure 29 gives 4 sets of curves of tubes built specially for determining the action of tubes as detectors and amplifiers. The plates and the filaments of these tubes were made as nearly as possible alike, but the grids were varied; the dimensions chosen were approximately the maximum and minimum considering the diameter of the plate. The exact dimensions and the number of turns of the grid are given in the figure; the standard length of filament and plate, and also the standard pitch of grid windings, were maintained for all four tubes. The results obtained confirmed the theory in every respect.

Inspection of the curves will immediately show that the tubes having 22-turn grids were good amplifiers but poor detectors; the rise of the curves is gradual and the radius of curvature at the knee of the curve, or in the region of operating grid potentials, is comparatively large—on the whole, both tubes proving of inferior value as detectors. Further comparison will show that of the tubes (numbers 13 and 17) number 17 is a better detector than the 13; on the other hand, tube 13 is by far the better amplifier. In other words, the farther the grid is from the filament, and the closer the grid is to the plate, the better are the amplifying qualities of the tube. Referring to the sketch of arrangement of elements in the tube, we may state that for the same number of turns in the grid the smaller is the ratio of $\frac{a}{b}$, the better is the amplification; thus, increasing this ratio will tend to bring out detector qualities at the expense of amplification. This statement holds equally well for the tubes 14 and 15, which are duplicates of 13 and 17 respectively, except for the number of grid turns, which in this case was 11 instead of 22.

Comparing now in pairs tubes 14 and 13, and 15 and 17, we will note that the larger the number of turns in the grid, the higher the resistance, the better the amplification quality, and conversely.

Picking out of the four tubes the best detector, or tube 15, we find that this tube has the grid of small diameter and small number of turns, or is the opposite extreme of tube 13, which is the best amplifier.

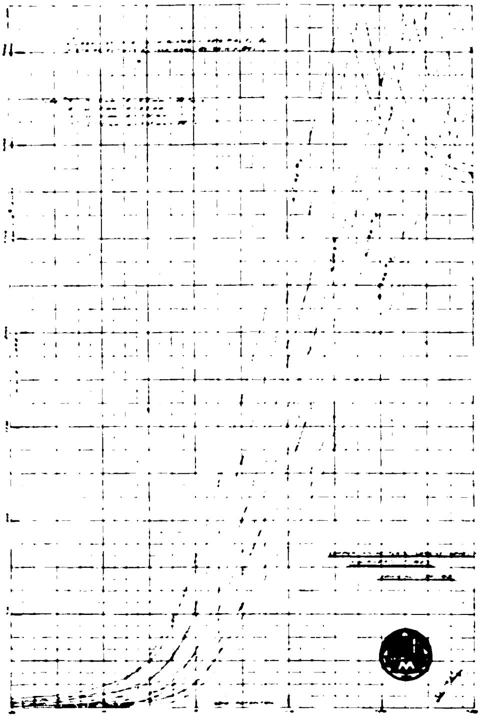


FIGURE 29

Further examination of the tube will reveal an interesting fact, namely that the curves of tubes 13 and 14, or the tubes with grids of larger diameter, do not show saturation within the limits of tests, while the tubes with grids of small diameter, numbers 15 and 17, indicate rather low saturation.

These and many other tests, in the authors' opinion, have proven conclusively that to obtain the best results in the use of tubes in radio, or any other work, at least two different types of tubes should be employed, selecting proper tubes designed for the purposes intended.

The mathematical formulas expressing the laws of action of tubes, as given to date, do not exactly explain the action, giving one or more constants in their general expression, which constants as indicated by the experiments, are not constants at all, but are variable functions of geometrical dimensions of the tube elements.

SUMMARY: A number of types of Moorhead tubes are described, together with the mode of testing them and the specifications to be met.

The tubes obtained are classified as detectors or amplifiers, which types the authors regard as separate and generally non-inclusive.

The effects of small variations of a number of the tube dimensions are exhaustively studied, and conclusions are drawn as to the effect of varying the various tube dimensions.

THE CATHODE-RAY OSCILLOGRAPH AND ITS APPLICATION IN RADIO WORK*

By

Lewis M. Hull

(Associate Physicist, United States Bureau of Standards,
Washington, D. C.).

The present article is not written with the intention of describing any novel developments in cathode-ray oscillographs or their use, but as a description of the present status of oscillographic practice with special emphasis upon the immense usefulness of the cathode-ray oscillograph in radio research. The work of the Bureau of Standards on this device is described. A bibliography of articles and books with the cathode-ray tube and its applications has been compiled, which is believed to be complete to 1920. Copies of this bibliography can be obtained from the Bureau of Standards, Washington, D. C.

Essentials of an Oscillograph Tube and Principles of Design

A cathode-ray oscillograph has five essential parts in addition to the glass containing bulb:—(1) a source of electrons which may be either a metal surface subjected to ionic bombardment or a body heated to incandescence; (2) a steady uni-directional potential difference—the accelerating voltage—for giving the electron stream a definite velocity in a straight line; (3) a filtering diafram for the purpose of forming the electron stream into a small beam or pointer; the action of the diafram may be supplemented or improved by the use of a magnetic concentrating field; (4) suitable plates and coils, for impressing upon the beam the electrostatic and magnetic fields, the behavior of which is to be studied; (5) a fluorescent screen for indicating visually the position of the beam. The screen may be coated with any of a number of compounds which fluoresce under electronic bombardment. Willemite (Zn_2SiO_4) and calcium tungstate ($CaWO_4$)

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have been found to be particularly suitable. Calcium tungstate glows with a bright blue color under the action of cathode rays, and the traces produced upon such a screen are particularly actinic and suitable for photography. The fluorescent spot formed by the cathode-ray pointer on willemite is greenish yellow, and better suited for visual observation.

Cathode-ray tubes may be divided into two general classes, according to the nature of the cathode, namely, hot-cathode and cold-cathode or Braun tubes. The general principles of design hold for all such apparatus, regardless of the methods employed in obtaining the stream of cathode particles. Approximate expressions relating the sensitivity of the tube, or the deflection per unit of intensity of the deflecting field with the geometrical constants of the tube and the accelerating voltage, can be readily deduced. Consider Figure 1, a diagrammatic sketch of the essential parts of a tube as they are arranged in practice. The steady accelerating voltage E_o (which may, in a cold-cathode tube, be also the *exciting voltage* altho the two functions of this potential difference are separate and independent) acts between the anode and the source. In practice the anode is grounded, and the space between anode and screen is maintained at ground potential, so that the mean velocity of the electrons in the direction of the screen is constant.

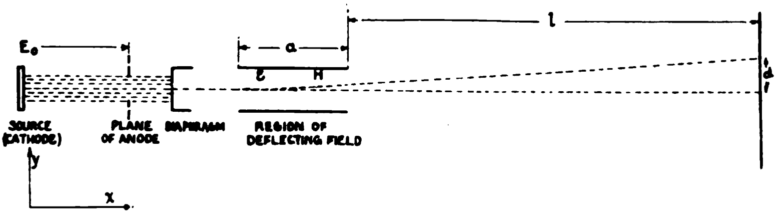

FIGURE 1

Let x be the horizontal co-ordinate parallel with the direction of propagation of the undeviated electrons; let y be the co-ordinate perpendicular to x and measured in the direction of the electrostatic field and perpendicular to the electromagnetic field. Let a be the length of the deflecting field, measured along x; E and H the intensities of the electrostatic and magnetic fields, assumed constant for a distance a; l, the distance from the deflecting field to the screen, and d_e, d_m the displacement of the fluorescent spot on the screen resulting from the action of the electrostatic and the electromagnetic fields, respectively. Then if v_0 be the constant velocity imparted to the electrons by the accelerating voltage E_0, e the charge on an electron, and m its mass at relatively low velocities, we have the voltage sensitivity of the tube:

$$\xi_e = \frac{a\,l}{2\,E_0\,s} \text{ cm. per volt.}$$

For the deflection in centimeters due to an impressed electromagnetic field of strength H we have:

$$d_m = \frac{H\,a\,l}{\sqrt{2E_0}}\sqrt{\frac{e}{m}} \tag{5}$$

These expressions are both based on the assumption that v_0 is constant and that the kinetic energy of motion of the electrons is equal to the energy acquired in the potential drop E_0. This assumption may be a rash one, if there is a considerable amount of ionizable gas left in the tube.

The magnetic field, H is such a complicated function of the number of turns in the deflecting coils, current in the coils, their size, shape, and spacing, that one cannot define a constant analogous to ξ_e for current sensitivity without such approximations as to make its applications to design calculations extremely limited. Chaffee has stated that with rectangular coils the distance apart of which is $\sqrt{2}$ times the spacing between their planes, the field between the coils is nearly uniform thruout their length. In any case the current sensitivity is increased by increasing the number of turns and the length of the coils. The merit of the tube can be indicated by its voltage sensitivity.

While these two formulas are not entirely rigorous they show that the sensitivity of a given tube for electrostatic and for magnetic deflections increases with the distance over which the deflecting field is applied, the distance between deflecting field and screen, and decreases with increasing value of the accelerating voltage.

The brightness of the fluorescent spot depends upon the number of electrons striking it and upon their velocity, the latter, as we have seen, being directly proportional to the square root of the accelerating voltage, E_0. Thus the general problem of design is a compromise between intensity of the fluorescent spot and the sensitivity. Constructional difficulties limit the increase in sensitivity which may be attained by increasing l; moreover, in cold cathode tubes there is necessarily left in the tube enough of ionizable gas to cause the velocity of the electrons to be sensibly diminished as l is increased. Thus, if the purpose for which the tube is to be used determines a maximum value of sensitivity, that is, a maximum value for E_o, then the proper brightness of the fluorescent spot must be attained by increasing the only other factor at our disposal, namely, the emission of electrons from the cathode. In a cold cathode tube the emission depends, for a given gas pressure, upon the exciting voltage. But unless the tube is complicated by the addition of an auxiliary anode, the exciting voltage and the accelerating voltage are identical and the emission cannot be be increased without increasing the velocity and decreasing the sensitivity. Thus the construction and use of a cold-cathode tube, the exciting voltage and accelerating voltages of which are the same, is chiefly a matter of experimental manipulation, and very little can be predicted theoretically. The pressure of the residual gas in the tube is an additional important factor. Enough gas must be present to allow the conduction of the exciting current to the anode, but the pressure must be sufficiently low to allow the electrons to pass down the tube without excessive hindrance. Hence, for a given value of the accelerating voltage, dictated by the requirements as to sensitivity, and necessarily determining the exciting voltage, there is a definite optimum value of pressure, for maximum intensity of the fluorescent spot.

The advantage of a tube having a cathode which emits electrons spontaneously is obvious in the light of the foregoing discussion. No exciting voltage is necessary. The rate of emission of electrons depends neither upon the accelerating voltage nor upon the gas pressure. The tube can be exhausted to the lowest possible degree, and the brightness of the spot can be controlled by controlling the temperature of the cathode, the magnitude of the accelerating voltage being determined entirely by the requirements of sensitivity. Thus from the standpoint of design and operation, tubes having a Wehnelt cathode would seem to be the ideal type. However, constructional difficulties involved in the manufacture of hot-cathode tubes are very great. The pressure in an enclosure of several liters capacity must be so low as to allow the electrons when accelerated by only a few hundred volts to travel from 20 to 50 centimeters (8 to 20 inches) in an undeviated path, and must be maintained over long periods of operation.

CONSTRUCTION OF COLD-CATHODE TUBES

The difficulties encountered in the construction and operation of two types of tubes are widely divergent and will be discussed separately.

In a cold-cathode tube the pressure, as has been mentioned, is a critical factor in determining the intensity of the cathode beam, and, to some extent, the sensitivity of the tube; hence, it is natural that the vacuum characteristics of the enclosed space should be very important in the construction of the tube. Certain other operational difficulties which were encountered by early investigators have, with the use of improved source of exciting voltage, become less irritating. Zenneck, Roschansky, and Varley who were compelled to use influence machines, were so troubled by electrostatic effects near the cathode and in the vicinity of the screen, both the building up of charges where none were desired, and the leakage of charge between points connected to the terminals of the exciter, that elaborate methods were used in attempts to obtain steady operation. It was found that positive charges collected on the glass near the cathode, causing discharges from the cathode to the glass and increasing the tendency for flash-overs in the tube. Zenneck and Roschansky made the cathodes of various peculiar shapes to minimize these effects, while Minton has stated that the presence of a film of absorbed gas around the cathode, while disadvantageous from the standpoint of maintenance of vacuum, tends to prevent the glass from being charged. This difficulty has been reduced to a minimum in later experiments, with steady sources of high direct voltage, a ground connection upon the anode and upon a tinfoil sheet or wire around the tube in the vicinity of the screen being sufficient to stabilize the conditions of discharge and electron flow down the tube.

In general it is observed that in cold-cathode tubes in which the vacuum is permanent, the pressure decreases with use. Rankin has shown that the hardening of such a tube with use is accentuated by the use of a strong magnetic concentrating field. On the other hand, tubes which are exhausted without certain precautions which insure the increase of vacuum after sealing off, soften with use, sometimes quite rapidly. There is no middle ground; it appears to be impossible so to exhaust a cold-cathode tube that the vacuum will remain constant thruout long periods of operation. In view of the fact that the vacuum cannot be increased by external means, the lesser evil is to exhaust the tube by such means as to produce an increasing vacuum, and to include a regulator tube of palladium or platinum in order to introduce minute quantities of air when the vacuum tends to increase. It has been demonstrated by Minton in conclusive experiments that the softening of a tube with use is due to the adsorption of a thin film of air over the surface of the glass and of the electrodes. Even if the tube be exhausted to less than a micron, that is, 0.001 mm. of mercury (the normal operating pressure is 3 to 10 microns) at atmospheric temperature, the passage of the discharge for only a few moments will release enough of this *adsorbed* film to raise the pressure above the best operating value. Hence it is essential that enough of the film be driven off during exhaustion that the pressure will not rise noticeably with use. This may be accomplished by heating the whole tube to a temperature just below the collapsing point of the glass and by operating the tube vigorously thruout the exhaust process. Without the heating during exhaustion, the air film invariably remains in the tube and causes trouble later. This process should not be confused with the heating of the electrodes to incandescence, which is done in an electron tube during exhaustion, and which is for the purpose of freeing the electrodes of *absorbed* gases. The electrodes in a cathode-ray tube are never subjected to high temperatures during use, and hence there is very slight possibility of the liberation of *absorbed* gases from them.

The cold-cathode tubes constructed at the Bureau of Standards are of the type shown in the diagrammatic sketch, Figure 2. A polished concave aluminum cathode is used, with radius of curvature somewhat less than the distance to the screen. The diafram and anode are combined in one piece and made of brass. A single aperture 0.025 cm. (0.01 inch) in diameter is used, the piece being built in two parts with a shielded opening around the outside edge, in order to allow the free passage of gas back and forth during exhaustion. Thin brass plates 8 cm. (3.4 inches) long, for electrostatic deflections were sealed into one tube. It was eventually found desirable, however, to facilitate exhaustion by reducing the amount of metal in the enclosure to a minimum. The gain in sensitivity resulting from a closer spacing between the plates does not justify their enclosure in the tube unless the tube be constructed for some special purpose. Screens of soda glass formed into circular plates were used instead of mica. The powdered calcium tungstate was sifted upon the surface which had previously been coated with china painters' varnish and the whole was heated until the powder became imbedded in the glass. The substitution of glass for mica is an expedient of doubtful advantage because the glass is much heavier and must be wired in place thru holes around the edge, to supporting posts which have previously been sealed inside the containing bulb. The drilling process usually starts minute cracks which speedily ruin the plate when it is heated, regardless of the care used in handling. The tubes proper were constructed of soft soda glass, which could be readily worked, and which has been found by Minton to be less conducive to adsorption of air than lead glass. The several parts of these tubes (fluorescent screens, aluminum cathodes, and brass anodes) were designed and constructed by the General Electric Company, and were purchased from the Pittsfield research laboratory of that Company.

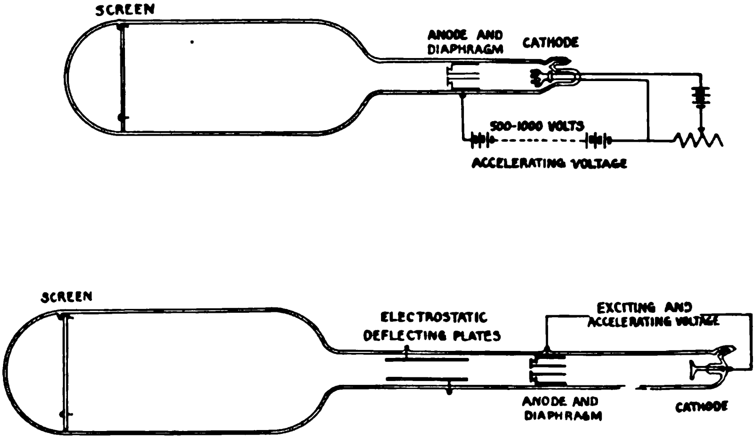

FIGURE 2

A Langmuir condensation pump in cascade with an oil-sealed rotary pump was used in the exhaustion. During exhaustion the tubes were kept at a temperature of 350° to 400° Centigrade in a specially constructed electric oven, and a heavy discharge was maintained between the anode and cathode. The chief reason for maintaining this discharge at known voltages was to indicate the condition of the vacuum. The assistance rendered by the discharge in reducing the vacuum is practically negligible, as Minton has found that in tubes exhausted while the discharge is maintained without heating, the vacuum invariably softens with use.

The electric oven used is made of galvanized iron and lined with quarter-inch asbestos board. It encloses a space four feet (1.2 m.) long by one foot (0.31 m.) square, which is maintained at a temperature of 400° Centigrade by twelve coils of "nichrome" wire so connected as to dissipate about 4 kilowatts at 110 volts.

The exhaustion of the tubes in this oven is rather a slow and laborious process owing to their large volume and to the large amount of enclosed metal. The high voltage discharge gives a sufficient indication of the progress and condition of the vacuum. Usually the exhaustion is far from complete when the Crookes dark space expands and evidence of cathode rays first appear. For a given exciting and accelerating voltage a definite optimum pressure is reached, as judged by the intensity of the fluorescent spot. This occurs when the positive column extends out from the cathode over a distance of from 0.5 to about 3 centimeters (0.2 to 1.2 inch). It is well to operate the tube heavily at this pressure before separating it from the pump.

EXCITATION OF COLD-CATHODE TUBES

By no means the least of the disadvantages of a cold-cathode tube employing the excitation method of obtaining electrons is the high direct voltage required. A voltage of 5,000 is the extreme minimum which has been found could be used in practice with a soft tube. If the gas pressure be high enough or higher than enough to allow an exciting voltage of 5,000 to produce a reasonably dense electron stream, there is danger of flash-overs, and the whole tube glows with ionized gas to such an extent as to make photography difficult. It has been found in practice that 10,000 to 20,000 volts are good compromise values. An exciting voltage of 10,000 together with the optimum degree of vacuum will provide enough electrons to produce a bright spot on the screen; the pressure for best production and propagation of electrons is such that the positive column is only a few centimeters long and the Geissler effects in the tube are not particularly brilliant. This value of accelerating voltage gives a theoretical voltage sensitivity of 0.011 cm. per volt in a 35-centimeter (13.6 inch) tube with 10 cm. (3.9 inches) deflecting plates spaced 1.5 cm. (0.59 inch) apart.

Few laboratories are equipped with storage cells enough to supply 10,000 volts, which would be the ideal source of supply, and other methods must be employed. Following the example of the early investigators, Ryan, Fleming, Dufour, and others have advocated the use of influence machines. In the first place, the only possible advantage attached to the use of an influence machine is the fact that the voltages supplied may be as high as 100,000 volts, and extremely hard tubes can be excited. If one wishes to measure dielectric power losses at high voltage it is necessary to use a hard tube of low sensitivity, and consequently the high exciting voltages are necessary. For ordinary oscillograph work, in which tubes of high sensitivity are required, it is essential that the accelerating voltage be kept low, and the electrostatic effects about the cathode, leakage, and general erratic behavior of an influence machine make it quite unsuitable. Moreover, after the shielding and drying precautions already mentioned are taken, a Wimshurst machine of sufficient number of plates and careful enough design to supply the necessary 50 to 500 micro-amperes without exceedingly vexatious and troublesome variations in the terminal voltage is about as uncommon as a 10,000-volt storage battery.

Minton has successfully used a mechanical rectifier with high-voltage alternating currents. It has been found at the Bureau of Standards that electron tubes are the ideal rectifiers for this purpose. Excellent two-electrode rectifying tubes ("kenotrons") are manufactured in this country by the General Electric Company, and the circuit shown in Figure 3 has been used as an exciting circuit. This system was first described by A. W. Hull ("Physical Review," March, 1916, page 405). A 110-30,000 volt transformer with a lead-in to the middle of the secondary winding is used at *T*. *C* is 0.04 μf. and *L* an iron-core choke coil of about 5 henrys inductance. The apparatus

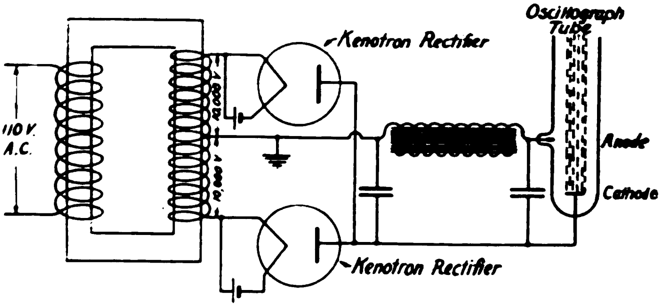

FIGURE 3

can be mounted on a suitable panel with separate transformers for the high-voltage supply and filament supply, forming a portable high voltage d. c. source which can be operated from 60-cycle mains. The power that can be taken from the rectifier, which is not of much importance in a cathode-ray tube, is limited only by the size of the kentrons used.

CONSTRUCTION OF HOT-CATHODE TUBES

Altho, as has been stated, the idea of utilizing a heated cathode as a source of electrons, thus making the supply independent of the accelerating voltage and easily controllable, was first conceived some time ago, the applications of this principle have been very limited. The difficulties are not in the conception nor in the theory, but in the construction, and so this discussion will be concerned chiefly with constructional details.

In a tube having an independently controllable source of electrons, it is not desirable to reduce the pressure to a certain optimum point of a few microns and then maintain it there, but to keep it at the lowest possible point all the time, since the electron flow is never assisted but always hindered by the pressure of gas. This was realized by Crooker who was compelled to keep his tube on the vacuum pump continually during his investigations. Perhaps the most successful work done in this country with hot-cathode tubes has been performed at Harvard University by Dr. Chaffee, Mr. R. F. Field, and their associates. They utilized tubes already manufactured by Muller-Uri, cutting off the constricted portion of the tube containing the platinum and aluminum electrodes, and utilizing the light, excellently coated and mounted fluorescent screens which are the chief merit of these German tubes. They used an anode made in the form of a ring, of diameter just small enough to go into the tube, and no filtering diafram whatever, depending entirely upon concentrating coils having a large number of ampere-turns to focus or concentrate the electron stream. The cathode is a thin strip of platinum, perhaps a millimeter (0.04 inch) wide, having a deposit of Wehnelt oxides about the size of the head of a pin deposited on the surface, the idea being to limit the emitting surface and depend upon focussing, rather than to provide a large supply of electrons and filter out the excess with a diafram with the possibility of increasing their concentration in the indicating ray. Being rather small, these tubes are comparatively easy to exhaust, and a fine sharp point is obtained on the fluorescent screen.

The first experiments along this line at the Bureau of Standards were performed with an experimental tube of small diameter, which could not have been used for oscillographic purposes. This tube was quite long, but the volume was small, in order to allow its rapid exhaustion. It was kept on the pump continuously and was so constructed as to expedite the removal of the cathode, in order to test different substances. The anode and diafram were separate, the anode being a thin ring of soft iron, and the diafram being also on an iron frame. The anode was connected to the sealed-in contact with a spiral of fine wire, the plan being to move the anode and diafram back and forth with a magnet after exhaustion of the tube, and determine, in connection with two concentrating coils of 250 turns each, placed around the tube, the optimum distance from screen and anode to diafram.

Tungsten and oxide-coated platinum cathodes of various forms were tried in this tube, the best type being a W-shaped platinum filament coated with barium and calcium oxides. Such a filament could be lighted to full brilliancy by a single lead cell. Tungsten filaments without an oxide coating have been used extensively by Coolidge in Rontgen-ray tubes, and Samson has decided that such filaments are useful in oscillograph tubes. However, it has been found that oxide-coated filaments give a much more bountiful supply of electrons, with less light, owing to the low filament temperature. As far as the vacuum characteristics are concerned, it is found that filaments coated with the composition used so successfully by the Western Electric Company in their electron tubes do not emit gases to a troublesome extent. Numerous experiments with varying distances between the electrodes, values of accelerating voltage, and configurations of the concentrating fields were very interesting. The best pressure for such work is considerably greater than the pressure maintained permanently in a tube. If there be gas enough present so that the electron stream ionizes the air on passing thru, the presence of the beam can be detected as a luminous blue streak, and can be much more easily focussed and adjusted. The effects of the concentrating coils can be seen at a glance. The bundle of "rays" emanating from the filament cathode and made visible by the ionized air can be formed into beautiful spiral figures by the action of the focussing coils. It was found, in general, that a concentrating field when used to best advantage is close to the diafram, and remote from the cathode. Apparently an ideal field for this purpose is one in which the lines of force are rectilinear and accurately parallel with the axle of the tube. If the lines of magnetic force are not parallel with the axis of the tube, the resultant force upon the moving electron due to its velocity and to the perpendicular component caused by the magnetic field will deflect its spiral path away from the axis of the tube as an axis of rotation and will cause the lines on the screen to depart from proportionality with the transverse fields.

The convolutions of the spiral path of the electron stream grow narrower as the field strength is increased. It seems to make little difference in the intensity of the spot whether the field is applied before the electrons encounter the diafram, directing the concentrated beam at the aperture in the diafram or after the small bundle of rays leaves the diafram.

The use of two focussing coils is superior to the use of one only in the matter of ease of adjustment. The same intensity and brightness of the indicating spot can be obtained eventually with one, as with two. It was found, moreover, that for a given accelerating voltage, the spacing between anode and diafram seemed to make no particular difference. An arrangement of concentrating coils for maximum brightness could be found for almost any position and spacing of the electrodes. It was finally decided that the simplest possible arrangement was quite adequate, that is, the use of one concentrating coil of about 500 ampere-turns, and a single electrode as diafram and anode, as in the cold cathode tubes. No special advantage was discovered in the experimental tube by having the anode and diafram separate. The following are the dimensions of a completed tube: screen to anode-diafram, 38 cm. (14.8 in.); anode-diafram to cathode, 11.4 cm. (4.44 in.); tube 3.2 cm. (1.25 in.) and 13 cm. (5.1 in.) in diameter; cathode about 0.6 cm. (0.23 in.) by 0.6 cm. (0.23 in.). A diagrammatic sketch of this tube is shown in Figure 2. The aperture in the diafram is only 0.027 cm. (0.01 in.) in diameter, and with the concentrating coil in the most favorable position a sharp spot about one millimeter (0.04 in.) in diameter is seen upon the screen. When used with an accelerating voltage of 500 volts a voltage sensitivity of about 0.25 cm. per volt has been obtained with this tube.

APPLICATIONS TO RADIO RESEARCH

The cathode ray oscillograph has been used in the radio laboratory of the Bureau of Standards in general testing work and also as an almost indispensable aid to research on radio frequency phenomena. It is employed for three different purposes: (1) to trace radio frequency current and voltage wave forms; (2) to trace the volt-ampere characteristics of a given device or network; (3) to synchronize radio frequency circuits.

The oscillograph cannot be used to trace voltage and current wave forms without apparatus accessory to that which is being investigated, since a time axis is always required. That is, if the voltage or current deflection is vertical, means for deflecting the spot horizontally at some lower frequency are necessary, in order that the curve be developed along an axis upon which the displacement is proportional to time or to some known function of time. Moreover, the vibration producing the time deflection must be accurately synchronized with the current or voltage oscillations, because the end of the cathode beam impinging on the screen may be traveling with a velocity of thousands of meters per second, and it must traverse exactly the same path in order to cause the screen to fluoresce. This synchronization of the time deflection with the current or voltage deflection is frequently a difficult matter, particularly where apparatus is under the test of which the behavior must not be altered by the influence of the measuring devices. When put to the uses (2) and (3) mentioned above, there is no such difficulty of synchronization, but careful design of the deflecting coils and plates is necessary in order to produce sufficient deflections without changing the constants of the device or network which is being investigated.

In Figures 4 and 5 are shown oscillograms taken as part of a test of a quenched spark set of unique construction submitted to the Bureau of Standards for test. The first five pictures show volt-ampere characteristics of the quenched gap when operating under different adjustments at a frequency of 500,000 (600 meters). Voltage across the closed circuit capacity is traced horizontally and current thru the closed oscillatory circuit is traced vertically, producing a fair approximation of a highly damped logarithmic spiral under best operating conditions. In the remaining six figures are shown current wave forms in the antenna circuit at 600 meters, for various adjustments of coupling and capacity in the closed circuit. The time axis is obtained in all cases by connecting the voltage deflecting plates across the primary condenser. The variation in voltage which develops the radio frequency wave train is not the 500-cycle supply voltage, but the rapid voltage rise as the condenser is charged, which takes place several times at the peak of the audio frequency

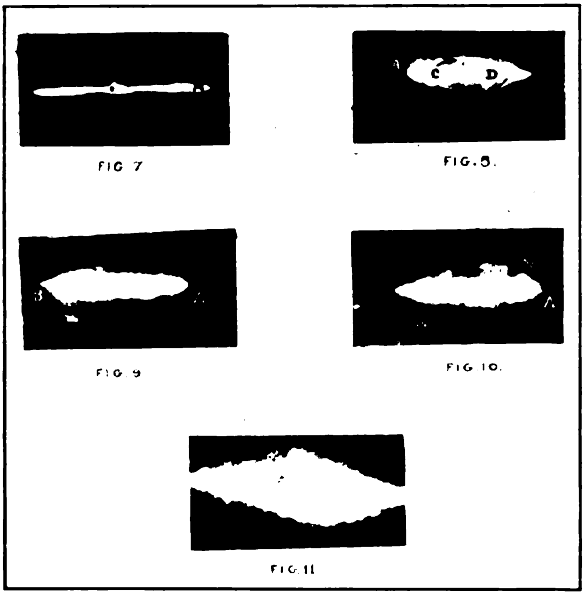

FIG 7. FIG. 8. FIG. 9. FIG 10. FIG. 11

FIGURE 4

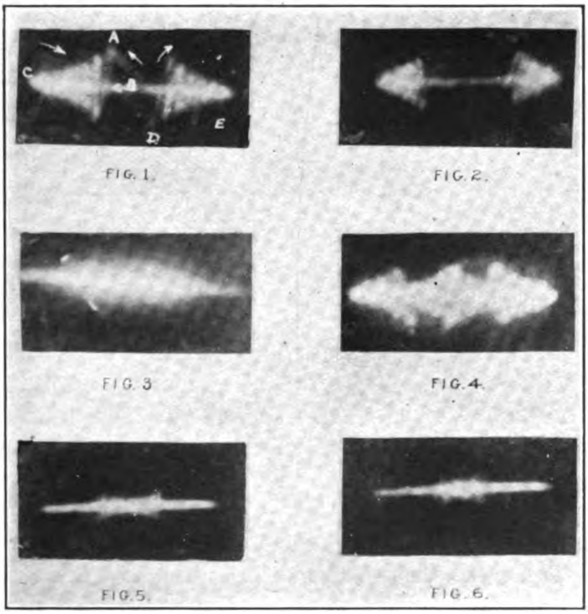

FIG. 1. FIG. 2. FIG. 3. FIG. 4. FIG. 5. FIG. 6.

FIGURE 5

cycle, and which correspond roughly to a frequency of 10,000 per second. It is true that these curves do not have the neat and clear-cut appearance of similar cathode ray photographs that have been published from time to time. It should be understood, however, that they are given as an indication of what can be done with a cathode ray tube as an aid to routine testing of spark apparatus which is admittedly erratic and uncertain in its behavior. It is not intended to portray the regular and consistent behavior of a well-designed spark set, but to show the possibilities in investigating faulty spark transmitters.

In Figure 6 are shown the envelopes of the antenna current of an electron tube transmitting set with alternating-current plate supply voltage, designed at the Bureau of Standards. The horizontal deflection is caused by the 500-cycle plate supply voltage, is sinusoidal and hence does not spread out the 300,000-cycle antenna current sufficiently to show the separate oscillations. All that was desired in this case was an indication of the antenna current envelope, which could not have been obtained by any other oscillograph without the use of a rectifier.

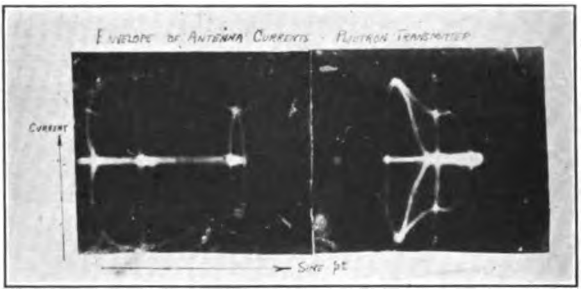

FIGURE 6

In Figure 7 are shown plate-current, grid-voltage characteristics of a lower power electron tube generator supplying about 3 watts output at wave lengths of 500 to 2,500 meters in an inductively coupled circuit. These diagrams were made some time ago, with a cold-cathode tube, and the figures were not sufficiently intense to be photographed. They were sketched on co-ordinate paper to correspond to co-ordinates ruled on the fluorescent screen. Cold-cathode tubes are, as a rule, too insensitive to obtain good volt-ampere characteristics of electron tubes, particularly when the space currents are involved. The plate and grid currents, being usually less than 0.05 ampere in amplitude, require deflecting coils of such magnitude as to affect and alter materially the characteristics of the output circuit. This is shown in these diagrams. The figures obtained at the longer wave lengths agree closely with the low frequency and static characteristics of the tube. However, as the frequency is increased, the reactance of the series deflecting coils in the plate circuit becomes comparable with the effective resistance of the output circuit and the plate current lags behind the grid voltage.

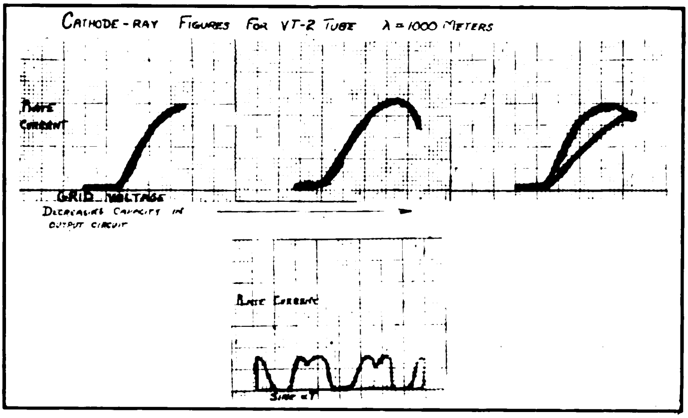

Figure 7

This may be complicated in practice by another effect, the results of which do not appear here, namely the distortion of the plate-current wave from its normal form as the deflecting coils become resonant to, and tend to choke out the various harmonics. In all generating circuits the load on the tube is a parallel resonance load, with the result that the harmonics of current from the tube due to saturation and rectification effect flow from the tube into the output system practically unchanged, maintaining a highly flattened and distorted wave form of space current, while the harmonics of voltage are choked out in the output system. Where a series reactance in the form of a deflecting coil is inserted in the circuit, its impedance to frequencies as high as the 5th harmonic of the radio frequency fundamental may be large compared with the 3,000 to 10,000-ohm tube resistance with the result that the normal operation of the system is altered by the elimination of the current harmonics.

At the present stage of development of the oscillograph it is impossible to obtain radio frequency detector and amplifier characteristics, since the operating range of such devices involves millivolts and microamperes, associated with high impedances. The only known method of determining dynamically the behavior of small tubes is by the use at audio frequencies of an Einthoven, or some other form of vibration galvanometer.

In Figure 8 are shown some current wave forms of an electron tube generator operating at about 3,000 meters. The strong harmonics in the space of the lower diagram of Figure 7 and the apparent absence of harmonics in the circulating output current are plainly evident (shown in Figure 8).

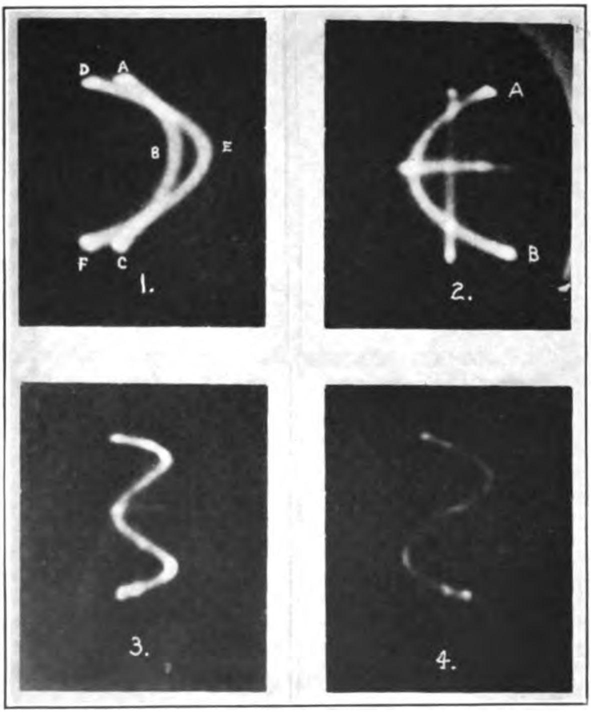

FIGURE 8

Deflections along the horizontal axis in these photographs are proportional to the sine of time, being produced by the alternating voltage across the condenser of a separate generating circuit which was tuned exactly to a lower frequency, a submultiple of the 500,000-cycle current, the wave form of which is being traced. Thus the figures are merely Lissajous figures in which the higher frequency is distorted by harmonics and is an integral multiple of the lower frequency. It is easy to trace from these photographs, by measuring properly spaced ordinates, the true current-time curves.

Beautiful and intricate Lissajous designs can be formed with two electron tube generating circuits and any cathode-ray tube in which the spot is bright and sharp. The ease with which the fundamental frequencies of such circuits can be continuously varied makes their use in this connection a fascinating as well as a profitable study. It has hitherto been considered possible to syntonize circuits only by resonance methods. This can be done with considerable accuracy using continuous waves, since measuring circuits of extremely low resistance can be employed. But the best accuracy which has been attained in comparing standard circuits at 600 meters, for example—is about 0.2 per cent., which means a discrepancy in frequencies of 500 cycles per second. It has even been a matter of conjecture whether electron-tube generators would maintain greater constancy of frequency than this from one minute to the next. Using the cathode-ray tube, however, it is possible to synchronize generating circuits to an accuracy of a small fraction of a cycle per second out of 500,000. In Figure 9 are shown copies of photographs of the figures obtained at random tuning two circuits to various frequency ratios. Deflections from the sinusoidal output current in one circuit are impressed against the equally sinusoidal output voltage from another circuit. Of course it is necessary to take elaborate precautions of grounding and shielding the coils and condensers from each other and from surrounding objects in order to attain nearly perfect syntonization. Even then the final adjustments can be readily made by changing the position of the operator's hand with respect to any ungrounded terminals, or about the generating tube itself, if the latter be left unshielded. A slight detuning of one of the circuits causes an apparent rotation of the figure about an axis in the plane of the photograph and parallel to the axis along which deflection at the lower of the two frequencies is taking place. One revolution of the figure per second corresponds to a frequency difference of one cycle; extremely careful shielding of the circuits from each other is necessary to prevent their pulling into synchronism and phase.

Such experiments are of interest in showing the constancy with which an electron tube oscillator will maintain a given radio frequency. If storage batteries be used to heat the filaments and to supply the plate circuits, and the tubes be allowed to operate for some time in order to become stabilized, the shielded circuits can be adjusted to a given ratio of frequency and left for minutes at a time without deviating as much as one cycle per second from these frequencies.

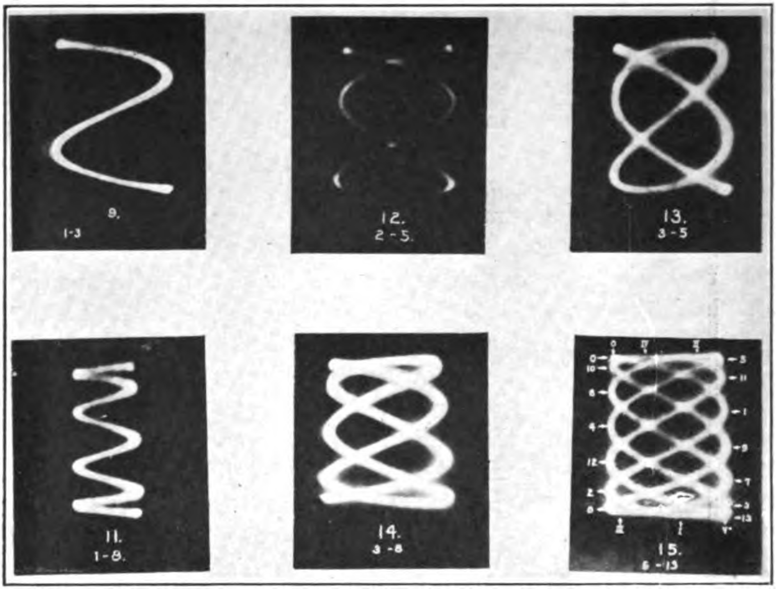

FIGURE 9

It becomes immediately apparent that radio frequency measurements which are performed by resonance methods can be performed with greater refinement by the use of an oscillograph for comparing frequencies. Consider the measurement of the distributed capacity of coils at radio frequencies. When using fixed inductance and fixed capacity in one circuit, with a standard variable condenser in the other, it was found that if the frequency of the variable circuit be increased from one ratio to another the capacity does not increase as the square of these ratios. For example, if the fixed circuit oscillates at a frequency n and if the variable circuit be tuned with a capacity C to a frequency n, the capacity for frequency $2n$ is slightly less than $4C$, the capacity for frequency $3n$ is less than $9C$, and so on. These discrepancies are due to the distributed capacity of the inductance in the variable circuit, and from two settings of the condenser the absolute value of this extremely small capacity can be calculated with greater accuracy than is possible by ordinary methods employing a wavemeter, using well-known formulas. ("Circular of the Bureau of Standards," number 74, page 101.)

The usefulness of the cathode-ray oscillograph in radio measurements is chiefly qualitative. Except when it is employed as an aid to frequency comparison between two circuits, precision measurements cannot be made, as the deflections can not be accurately measured when photographed. It is as an aid to research, permitting visual observations of phenomena hitherto unseen and furnishing qualitative data for new ideas and new theories, that the cathode-ray oscillograph performs a service that can be achieved by no other device.

Washington, D. C., February 20, 1920.

SUMMARY: The general construction and details of the design of cathode ray tubes are given. The brightness of the spot obtained, the sensitivity of the tube, and its behavior in use are described. The various excitation sources available are compared. A number of applications of such tubes to radio research (for example, spark gap characteristics, and associate synchronizing of oscillating triodes) are described.

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FREQUENCIES AND DAMPING FACTORS OF COUPLED CIRCUITS*

By

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In nearly all of the many investigations of the subject of coupled circuits, the discussions were largely limited to the evaluation of the frequency constants and in some cases the determination of the current amplitudes; also only magnetic coupling was generally considered. The matter of damping factors was generally ignored, and the reason for it is the mathematical complications introduced in any attempt to obtain the complete solution of coupled circuits.

In the study, however, of oscillatory currents it is frequently of great importance to have some knowledge of the damping factors; it may be very helpful in investigations relating to oscillatory currents due to local disturbances or static effects.

In this paper a comparatively simple and effective method is developed which is applicable for the determination of the frequency and damping constants of any electrical system of two degrees of freedom, and the work is given in detail for the cases of magnetic coupling, direct coupling and electrostatic coupling.

MAGNETIC COUPLING

The circuit equations are as follows:

$$\left.\begin{aligned} L_1\frac{d^2 I_1}{dt^2}+R_1\frac{d I_1}{dt}+\frac{I_1}{C_1}+M\frac{d^2 I_2}{dt^2}=0 \\ L_2\frac{d^2 I_2}{dt^2}+R_2\frac{d I_2}{dt}+\frac{I_2}{C_2}+M\frac{d^2 I_1}{dt^2}=0 \end{aligned}\right\} \quad (1)$$

Assume $I_1=A\varepsilon^{\lambda t}$, $I_2=B\varepsilon^{\lambda t}$ and substituting in (1), we get

$$\left.\begin{aligned} (L_1 C_1 \lambda^2+R_1 C_1 \lambda+1)\,A+M\,C_1\,\lambda^2 B=0, \\ (L_2 C_2 \lambda^2+R_2 C_2 \lambda+1)\,B+M\,C_2\,\lambda^2 A=0. \end{aligned}\right\} \quad (2)$$

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* Received by the Editor, September 20, 1919.

Eliminating $\frac{A}{B}$ we get a fourth degree equation as follows:

$$C_1 C_2 (L_1 L_2 - M^2) \lambda^4 + C_1 C_2 (L_1 R_2 + L_2 R_1) \lambda^3 + (L_1 C_1 + L_2 C_2 + R_1 R_2 C_1 C_2) \lambda^2 + (R_1 C_1 + R_2 C_2) \lambda + 1 = 0. \tag{3}$$

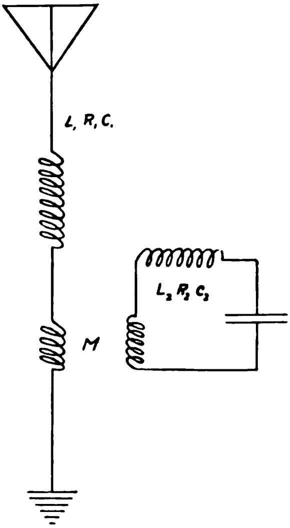

FIGURE 1

Since the currents are of damped oscillatory character, λ is a complex quantity, the real term the damping factor, and the imaginary term the frequency constant of the system. Putting $\lambda = \alpha + j\beta$, we get

$$\lambda^2 = \alpha^2 - \beta^2 + j\,2\alpha\beta,$$
$$\lambda^3 = \alpha^3 - 3\alpha\beta^2 + 3j\alpha^2\beta - j\beta^3,$$
$$\lambda^4 = \alpha^4 - 6\alpha^2\beta^2 + \beta^4 + j\,4\alpha^3\beta - 4j\alpha\beta^3.$$

In all high frequency circuits α is small in comparison with β, and by neglecting α^2 in comparison with β^2 the error introduced is extremely small, so that to a very high degree of approximation we may write,

$$\left.\begin{aligned} \lambda &= \alpha + j\beta, \\ \lambda^2 &= -\beta^2 + 2j\alpha\beta, \\ \lambda^3 &= -3\alpha\beta^2 - j\beta^3, \\ \lambda^4 &= \beta^4 - 4j\alpha\beta^3. \end{aligned}\right\} \tag{4}$$

Substituting the values of λ from (4) into (3), we get

$$C_1 C_2 (L_1 L_2 - M^2)(\beta^4 - j 4 \alpha \beta^3) - C_1 C_2 (L_1 R_2 + L_2 R_1)(3 \alpha \beta^2 + j \beta^3) + (L_1 C_1 + L_2 C_2 + R_1 R_2 C_1 C_2)(-\beta^2 + j 2 \alpha \beta) + (R_1 C_1 + R_2 C_2)(\alpha + j \beta) + 1 = 0. \tag{5}$$

Separating the reals and imaginaries, we have

$$C_1 C_2 (L_1 L_2 - M^2) \beta^4 - \{3 \alpha C_1 C_2 (L_1 R_2 + L_2 R_1) + L_1 C_1 + L_2 C_2 + R_1 R_2 C_1 C_2\} \beta^2 + (R_1 C_1 + R_2 C_2) \alpha + 1 = 0, \tag{6}$$

$$-4 C_1 C_2 (L_1 L_2 - M^2) \alpha \beta^2 - C_1 C_2 (L_1 R_2 + L_2 R_1) \beta^2 + (L_1 C_1 \; L_2 C_2 + R_1 R_2 C_1 C_2) 2 \alpha + (R_1 C_1 + R_2 C_2) = 0. \tag{7}$$

The resistance terms in equation (6) are very small in comparison with the other terms, hence to a very high degree of approximation equation (6) reduces to

$$C_1 C_2 (L_1 L_2 - M^2) \beta^4 - (L_1 C_1 + L_2 C_2) \beta^2 + 1 = 0 \tag{8}$$

and

$$\beta^2 = \frac{L_1 C_1 + L_2 C_2 \pm \sqrt{(L_1 C_1 - L_2 C_2)^2 + 4 M^2 C_1 C_2}}{2 C_1 C_2 (L_1 L_2 - M^2)}. \tag{9}$$

For resonance condition, $L_1 C_1 = L_2 C_2 = L C$, equation (9) reduces to

$$\beta^2 = \frac{2 L C \pm 2 M \sqrt{C_1 C_2}}{2 L^2 C^2 \left(1 - \frac{M^2}{L_1 L_2}\right)},$$

$$= \frac{1}{L C (1 \mp \rho)}, \tag{10}$$

where $\rho = \dfrac{M}{\sqrt{L_1 L_2}}.$

The values of β^2 given by (9) and (10) are the well-known expressions for the frequency constants of magnetically-coupled circuits; ρ is the coupling coefficient.

By equation (7), we have

$$\{2 L_1 C_1 + 2 L_2 C_2 + 2 R_1 R_2 C_1 C_2 - 4 C_1 C_2 (L_1 L_2 - M^2) \beta^2\} \alpha = C_1 C_2 (L_1 R_2 + L_2 R_1) \beta^2 - R_1 C_1 - R_2 C_2$$

and

$$\alpha = \frac{C_1 C_2 (L_1 R_2 + L_2 R_1) \beta^2 - R_1 C_1 - R_2 C_2}{2 L_1 C_1 + 2 L_2 C_2 + 2 R_1 R_2 C_1 C_2 - 4 C_1 C_2 (L_1 L_2 - M^2) \beta^2}. \tag{11}$$

Introducing in (11) the values of β^2 from (9) or (10), we get the complete expressions of the damping factors expressed in terms of the electrical constants of the circuits. In any given case it is simpler to obtain first the numerical values of β^2 and substituting in (11) to obtain the values of the damping factors. For the resonance condition, a considerable simplification of (11) can be obtained. We have

$$C_1 C_2 (L_1 R_2 + L_2 R_1)\, \beta^2 = \frac{C_1 C_2 (L_1 R_2 + L_2 R_1)}{L C (1 \pm \rho)}$$

$$= \frac{R_2 C_2 + R_1 C_1}{1 \mp \rho},$$

$$4 C_1 C_2 (L_1 L_2 - M^2)\, \beta^2 = \frac{4 L^2 C^2 (1 - \rho^2)}{L C (1 \mp \rho)} = 4 L C (1 \pm \rho) \cdot$$

Substituting above values in (11), we get

$$\alpha = \frac{(R_2 C_2 + R_1 C_1)\left(-1 + \frac{1}{1 \mp \rho}\right)}{4 L C + 2 R_1 R_2 C_1 C_2 - 4 L C (1 \pm \rho)},$$

$$= \frac{\pm \rho\, (R_2 C_2 + R_1 C_1)}{(2 R_1 R_2 C_1 C_2 \mp 4 L C \rho)\, (1 \mp \rho)} \cdot \tag{12}$$

Equation (12) is the complete expression for the damping factors of magnetically-coupled circuits at resonance condition. In all practical cases $R_1 R_2 C_1 C_2$ is very small in comparison with the term $L\ C\ \rho$, and equation (12) simplifies still further to the following:

$$\alpha = -\frac{\left(\frac{R_2}{4 L_2} + \frac{R_1}{4 L_1}\right)}{1 \mp \rho}. \tag{13}$$

DIRECT COUPLED CIRCUITS

The circuit arrangement is shown in Figure 2 and the circuit equations are as follows:

$$\left.\begin{aligned} L_o \frac{d^2 I_o}{dt^2} + R_o \frac{d I_o}{dt} + \frac{I_o}{C_o} + L_2 \frac{d^2 I_2}{dt^2} + R_2 \frac{d I_2}{dt} &= 0, \\ L_o \frac{d^2 I_o}{dt^2} + R_o \frac{d I_o}{dt} + \frac{I_o}{C_o} + L_1 \frac{d^2 I_1}{dt^2} + R_1 \frac{d I_1}{dt} + \frac{I_1}{C_1} &= 0 \cdot \end{aligned}\right\} \tag{14}$$

Also,

$$I_o = I_1 + I_2.$$

Substituting the above value of I_o in (14) and rearranging, we get

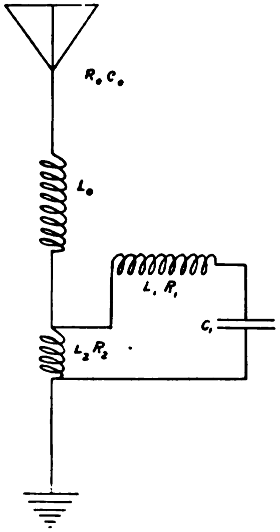

FIGURE 2

$$\left.\begin{aligned}
&L_o\frac{d^2I_1}{dt^2}+R_o\frac{dI_1}{dt}+\frac{I_1}{C_o}+(L_o+L_2)\frac{d^2I_2}{dt^2}+(R_o+R_2)\frac{dI_2}{dt}\\
&\qquad+\frac{I_2}{C_o}=0,\\
&(L_o+L_1)\frac{d^2I_1}{dt^2}+(R_o+R_1)\frac{dI_1}{dt}+\left(\frac{1}{C_o}+\frac{1}{C_1}\right)I_1+L_o\frac{d^2I_2}{dt^2}\\
&\qquad+R_o\frac{dI_2}{dt}+\frac{I_2}{C_o}=0.
\end{aligned}\right\}\qquad(15)$$

Assuming as solutions, $I_1=A\varepsilon^{\lambda t}$ and $I_2=B\varepsilon^{\lambda t}$, and eliminating $\frac{A}{B}$ from the above two equations, we get a fourth degree equation in λ as follows:

$$\left.\begin{aligned}
&(L_o L_1+L_o L_2+L_1 L_2)\lambda^4+(L_oR_1+L_2R_o+L_2R_1+L_1R_o\\
&\qquad+L_oR_2+L_1R_2)\lambda^3+\left(\frac{L_2}{C_o}+\frac{L_o}{C_1}+\frac{L_2}{C_1}+\frac{L_1}{C_o}+R_oR_2\right.\\
&\qquad\left.+R_1R_o+R_1R_2\right)\lambda^2+\left(\frac{R_2}{C_o}+\frac{R_o}{C_1}+\frac{R_2}{C_1}+\frac{R_1}{C_o}\right)\lambda\\
&\qquad+\frac{1}{C_1C_o}=0.
\end{aligned}\right\}\qquad(16)$$

Substituting for λ the complex quantity $\alpha+j\beta$, neglecting α^2 in comparison with β^2, and then separating the real and imaginary terms, we get the following two equations:

$$(L_oL_1+L_oL_2+L_1L_2)\beta^4-\Big\{3\alpha(L_oR_1+L_2R_o+L_2R_1+L_1R_o$$
$$+L_oR_2+L_1R_2)+\frac{L_2+L_1}{C_o}+\frac{L_o+L_2}{C_1}+R_oR_2+R_oR_1$$
$$+R_1R_2\Big\}\beta^2+\left(\frac{R_2+R_1}{C_o}+\frac{R_o+R_2}{C_1}\right)\alpha+\frac{1}{C_1C_o}=0, \qquad (17)$$

$$4(L_oL_1+L_oL_2+L_1L_2)\alpha\beta^2+(L_oR_1+L_2R_o+L_2R_1$$
$$+L_1R_o+L_oR_2+L_1R_2)\beta^2-2\left(\frac{L_2+L_1}{C_o}+\frac{L_o+L_2}{C_1}\right.$$
$$\left.+R_oR_2+R_oR_1+R_1R_2\right)\alpha-\frac{R_2+R_1}{C_o}-\frac{R_o+R_2}{C_1}=0. \qquad (18)$$

Neglecting the resistance terms in equation (17), these being extremely small in comparison with the other terms, it reduces to

$$C_1C_o(L_oL_1+L_oL_2+L_1L_2)\beta^4-(L_2C_1+L_oC_0+L_2C_o$$
$$+L_1C_1)\beta^2+1=0, \qquad (19)$$

and

$$\beta^2=\frac{(L_2C_1+L_oC_o+L_2C_o+L_1C_1)\pm\sqrt{(L_2C_1+L_oC_o+L_2C_o+L_1C_1)^2-4C_1C_o(L_oL_1+L_oL_2+L_1L_2)}}{2C_1C_o(L_oL_1+L_oL_2+L_1L_2)} \qquad (20)$$

Equation (20) is the general expression for the two frequency constants of direct coupled circuits.

For the resonance condition,

$$(L_o+L_2)C_o=(L_1+L_2)C_1=LC,$$

equation (20) reduces to

$$\beta^2=\frac{1\pm\sqrt{1-\left(\frac{L_o}{L_o+L_2}+\frac{L_1L_2}{(L_o+L_2)(L_1+L_2)}\right)}}{LC\left[\frac{L_o}{L_o+L_2}+\frac{L_1L_2}{(L_o+L_2)(L_1+L_2)}\right]}. \qquad (21)$$

Put, for brevity,

$$\rho^2=1-\frac{L_o}{L_o+L_2}-\frac{L_1L_2}{(L_o+L_2)(L_1+L_2)},$$
$$=\frac{L_2^2}{(L_o+L_2)(L_1+L_2)}, \qquad (22)$$

and substitute in equation (21), we get

$$\beta^2=\frac{1\pm\rho}{LC(1-\rho^2)},$$
$$=\frac{1}{LC(1\mp\rho)}. \qquad (23)$$

The expression for the frequency constants is identical in form to the one obtained for the magnetically-coupled circuits.

and the expression for ρ given by (22) may be defined as the coefficient of coupling in direct-coupled circuits.

From equation (18), we get the value of α, the damping factor, which is as follows:

$$\alpha=\frac{C_oC_1\,(L_o\,R_1+L_2\,R_o+L_2\,R_1+L_1\,R_o+L_o\,R_2+L_1\,R_2)\beta^2 -(R_2C_1+R_oC_o+R_2C_o+R_1C_1)}{2\,(L_2C_1+L_oC_o+L_2C_o+L_1C_1+R_oR_2C_o\,C_1+R_oR_1\,C_oC_1 +R_1\,R_2C_oC_1)-4C_oC_1\beta^2\,(L_o\,L_1+L_o\,L_2+L_1L_2)}. \tag{24}$$

Equation (24) is the complete expression for the damping factors. Knowing the values of β^2 as given by (21) or (23), the values of α can be readily evaluated for any given case. For resonance condition, and neglecting the terms

$$R_o\,R_2\,C_o\,C_1+R_o\,R_1\,C_o\,C_1+R_1\,R_2\,C_o\,C_o$$

as being very small in comparison with $L\,C$, equation (24) reduces to:

$$\alpha=\frac{L^2C^2\beta^2\left\{\frac{R_1}{L_1+L_2}+\frac{R_o}{L_o+L_2}+\frac{R_2\,(L_1+L_o)}{(L_o+L_2)\,(L_1+L_2)}\right\} -(R_2C_1+R_1C_1+R_oC_o+R_2C_o)}{4\,LC\,\{1-LC\,\beta^2\,(1-\rho^2)\}}. \tag{25}$$

Substituting the value of β^2 from (23), the above equation reduces to

$$\alpha=\frac{1}{4\,(1\mp\rho)\,(L_1+L_2)\,\rho}\left\{R_1+R_o\frac{L_1+L_2}{L_o+L_2}+R_2\frac{L_1+L_o}{L_o+L_2}\right\} \pm\frac{1}{4\rho}\left\{\frac{R_2+R_1}{L_1+L_2}+\frac{R_o+R_2}{L_o+L_2}\right\}, \tag{26}$$

which is the complete expression for the damping factors at resonance condition. In all practical cases, L_2 is small in comparison with either L_0 or L_1, and by neglecting L_2, equation (26) simplifies to the following:

$$\alpha=\frac{1}{\mp4\,\rho\,L_1\,(1\mp\rho)}\left\{R_1+R_o\frac{L_1}{L_o}\right\}\pm\frac{1}{\rho}\left\{\frac{R_1}{L_1}+\frac{R_o}{L_o}\right\}$$

$$=-\frac{R_1+R_o\dfrac{L_1}{L_o}}{4L_1(1\mp\rho)}$$

$$=-\frac{\dfrac{R_1}{4\,L_1}+\dfrac{R_o}{4\,L_o}}{1\mp\rho}. \tag{27}$$

The expression for the damping factors given by (27) is identical in form to the expression obtained for the case of magnetically coupled circuits.

ELECTROSTATIC COUPLING

The circuit arrangement is shown in Figure 3, and the circuit equations are as follows:

$$\left.\begin{aligned}
&L_o\frac{d^2I_o}{dt^2}+R_o\frac{dI_o}{dt}+\frac{I_o}{C_o}+\frac{I_1}{C_1}=0,\\
&L_o\frac{d^2I_o}{dt^2}+R_o\frac{dI_o}{dt}+\frac{I_o}{C_o}+\frac{I'}{C'}+\frac{I_2}{C_2}=0,\\
&L_o\frac{d^2I_o}{dt^2}+R_o\frac{dI_o}{dt}+\frac{I_o}{C_o}+\frac{I'}{C'}+L_2\frac{d^2I_3}{dt^2}+R_2\frac{dI_3}{dt}=0.
\end{aligned}\right\}\qquad(28)$$

We also have the auxiliary current relations,

$$\left.\begin{aligned}
&I'=I_2+I_3,\\
&I_o=I'+I_1=I_1+I_2+I_3.
\end{aligned}\right\}\qquad(29)$$

Assuming

$$I_1=A\,\varepsilon^{\lambda t},\quad I_2=B\,\varepsilon^{\lambda t},\quad I_3=D\,\varepsilon^{\lambda t},$$

and also substituting the relations given by (29), equations (28) take the following form:

$$\left.\begin{aligned}
&\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}+\frac{1}{C_1}\right)A+\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}\right)B+\Big(L_o\lambda^2\\
&\qquad+R_o\lambda+\frac{1}{C_o}\Big)D=0,\\
&\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}\right)A+\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}+\frac{1}{C'}+\frac{1}{C_2}\right)B+\Big(L_o\lambda^2\\
&\qquad+R_o\lambda+\frac{1}{C_o}+\frac{1}{C'}\Big)D=0,\\
&\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}\right)A+\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}+\frac{1}{C'}\right)B+\Big(L_o\lambda^2\\
&\qquad+R_o\lambda+\frac{1}{C_o}+L_2\lambda^2+R_2\lambda+\frac{1}{C'}\Big)D=0.
\end{aligned}\right\}\qquad(30)$$

Eliminating A from the above three equations, we get

$$\begin{aligned}
&\Big\{\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}\right)^2-\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}+\frac{1}{C_1}\right)\Big(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}\\
&\qquad+\frac{1}{C'}+\frac{1}{C^2}\Big)\Big\}B+\Big\{\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}\right)^2-\Big(L_o\lambda^2+R_o\\
&\qquad+\frac{1}{C_o}+\frac{1}{C_1}\Big)\left(L_o\lambda^2+R_o\lambda+\frac{1}{C_o}+\frac{1}{C'}\right)\Big\}D=0.
\end{aligned}\qquad(31)$$

$$\frac{1}{C_2}B-(L_2\lambda^2+R_2\lambda)\,D=0.$$

Eliminating $\dfrac{B}{D}$ from the above two equations, we get a fourth degree equation in λ as follows:

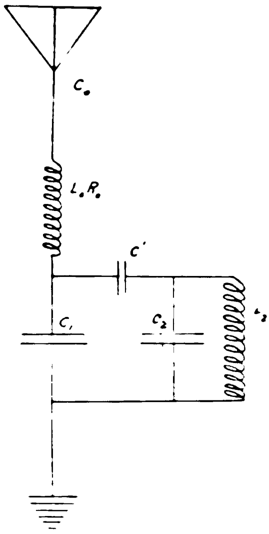

FIGURE 3

$$L_0L_2(C_1C_2+C_1C'+C'C_2)\lambda^4+(L_2R_0+L_0R_2)(C_1C_2+C_1C'$$
$$+C_2C')\lambda^3+\left\{\left(\frac{L_2}{C_0}+R_0R_2\right)(C_1C_2+C_1C'+C_2C')+L_2(C'$$
$$+C_2)+L_0(C'+C_1)\right\}\lambda^2+\left\{\frac{R_2}{C_0}(C_1C_2+C_1C'+C_2C')+R_2(C_2$$
$$+C')+R_0(C_1+C')\right\}\lambda+\frac{C_1}{C_0}+\frac{C'}{C_0}+1=0. \qquad (32)$$

Substituting for λ the complex quantity $\alpha+j\beta$ and separating reals and imaginaries we get the following two equations:

$$L_0L_2(C_1C_2+C_1C'+C'C_2)\beta^4-\left\{3\alpha(L_2R_0+L_0R_2)(C_1C_2+C_1C'\right.$$
$$+C_2C')+\left(\frac{L_2}{C_0}+R_0R_2\right)(C_1C_2+C_1C'+C_2C')+L_2(C'+C_2)$$
$$\left.+L_0(C'+C_1)\right\}\beta^2+\alpha\left\{\frac{R_2}{C_0}(C_1C_2+C_1C'+C_2C')+R_2(C_2$$
$$\left.+C')+R_0(C_1+C')\right\}+\frac{C_1}{C_0}+\frac{C'}{C_0}+1=0. \qquad (33)$$

$$-4\alpha\beta^2L_0L_2(C_1C_2+C_1C'+C'C_2)-\beta^2(L_2R_0+L_0R_2)(C_1C_2$$
$$+C_1C'+C_2C')+2\alpha\left\{\left(\frac{L_2}{C_0}+R_0R_2\right)(C_1C_2+C_1C'+C_2C')\right.$$
$$\left.+L_2(C'+C_2)+L_0(C'+C_1)\right\}+\frac{R_2}{C_0}(C_1C_2+C_1C'+C_2C')$$
$$+R_2(C_2+C')+R_0(C_1+C')=0. \qquad (34)$$

Substituting the above value of L_0 in (35), we get

$$L_2^2 C_2 (C_o+C_1)\left(\frac{C_2C_1+C_1C'+C_2C'}{C_oC_1}\right)\beta^4 - L_2\left\{\frac{C_2C_1+C_1C'+C_2C'}{C_o}+C_2+C'+\frac{C_2(C_o+C_1)(C_1+C')}{C_oC_1}\right\}\beta^2$$
$$+\frac{C_1+C'+C_o}{C_o}=0, \tag{37}$$

which simplifies to the following:

$$L^2C^2\left(C_1+\frac{C_1C'}{C_2}+C'\right)\beta^4 - LC\left(2C_1+\frac{C_1C'}{C_2}+C'+\frac{C_1C'}{C_1+C_o}\right)\beta^2+C_1\left(1+\frac{C'}{C_1+C_o}\right)=0 \tag{38}$$

and

$$\beta^2=\frac{\left(2C_1+\frac{C_1C'}{C_2}+C'+\frac{C_1C'}{C_1+C_o}\right)\pm\sqrt{\left(2C_1+\frac{C_1C'}{C_2}+C'+\frac{C_1C'}{C_1+C_o}\right)^2-4C_1\left(1+\frac{C'}{C_1+C_o}\right)\left(C_1+\frac{C_1C'}{C_2}+C'\right)}}{2LC\left(C_1+\frac{C_1C'}{C_2}+C'\right)}. \tag{39}$$

Expanding the terms under the radical and rearranging, we get

$$\beta^2=\frac{\left(2+\frac{C'}{C_2}+\frac{C'}{C_1}+\frac{C'}{C_1+C_o}\right)\pm\sqrt{\left(\frac{C'}{C_2}+\frac{C'}{C_1}\right)^2-\frac{2C'}{C_1+C_o}\left(\frac{C'}{C_1}+\frac{C'}{C_2}\right)+\frac{C'}{(C_1+C_o)^2}}}{2LC\left(1+\frac{C'}{C_2}+\frac{C'}{C_1}\right)}. \tag{40}$$

Put, for brevity,

$$\left.\begin{aligned}\frac{C'}{C_1}+\frac{C'}{C_2}&=K_1\\ \frac{C'}{C_1+C_o}&=K_2\end{aligned}\right\}, \tag{41}$$

In equation (33) all the resistance terms are very small and can be neglected, and it reduces to the following:

$$L_o L_2 (C_1 C_2 + C_1 C' + C_2 C') \beta^4 - \left\{ \frac{L_2}{C_o} (C_1 C_2 + C_1 C' + C_2 C') + L_2 (C' + C_2) + L_o (C' + C_1) \right\} \beta^2 + \frac{C_1 + C'}{C_o} + 1 = 0. \qquad (35)$$

The value of β can be readily obtained by solving the above biquadratic equation. The formula obtained, however, will be difficult of interpretation because of its complex form. It is, therefore, desirable in this case to limit the discussion to the resonance condition. If it should be necessary in some cases to obtain the values of the frequency constants for the non-resonance condition, it would be simpler to substitute the numerical values for the different L's and C's in (35) and solving for β.

For resonance, we have

$$L_2 C_2 = L_o \frac{1}{\frac{1}{C_o} + \frac{1}{C_1}} = \frac{L_o C_o C_1}{C_o + C_1} = LC. \qquad (36)$$

$$L_o = \frac{L_2 C_2 (C_o + C_1)}{C_o C_1}.$$

and substitute in (40). We finally get the following expression for the frequency constants:

$$\beta^2 = \frac{(2+K_1+K_2) \pm \sqrt{K_1{}^2-2\,K_1\,K_2+K_2{}^2}}{2\,LC\,(1+K_1)},$$
$$= \frac{2+(K_1+K_2)\pm(K_1-K_2)}{2\,L\,C\,(1+K_1)}. \tag{42}$$

The damping factors of the system can be obtained from equation (34).

$$\alpha = \frac{(L_2\,R_o+L_o\,R_2)\,(C_1C_2+C_1C'+C_2C')\,\beta^2-\dfrac{R_2}{C_o}(C_1C_2+C_1C'+C_2C')-R_2\,(C_2+C')-R_o\,(C_1+C')}{2\left\{\left(\dfrac{L_2}{C_o}+R_o\,R_2\right)(C_2C_1+C_1C'+C_2C')+L_2\,(C_2+C')+L_o\,(C_1+C')\right\}-4\,L_o\,L_2\,(C_1C_2+C_1C'+C_2C')\,\beta^2}. \tag{43}$$

If the values of β^2 and the electrical constants of the circuits are given, the values of the damping factors are completely determined by the above equation.

For resonance condition

$$L_o = \frac{L_2C_2\,(C_1+C_o)}{C_o\,C_1},$$

and also neglecting $R_o\,R_2$ in comparison with $\frac{L_2}{C_o}$, equation (43) takes the form:

$$\alpha = \frac{L_2R_o(C_2C_1+C_1C'+C_2C')\beta^2+L_2\,R_2C_2\dfrac{(C_o+C_1)}{C_o\,C_1}(C_2C_1+C_1C'+C_2C')\beta^2-R_2\left(\dfrac{C_1C_2+C_1C'+C_2C'}{C_o}+C_2+C'\right)-R_o(C_1+C')}{2\,L_2\left\{\dfrac{C_2C_1+C_1C'+C_2C'}{C_o}+C_2+C'+\dfrac{C_2\,(C_o+C_1)}{C_o\,C_1}\,(C_1+C')\right\}-4\,L_2{}^2\dfrac{C_2\,(C_o+C_1)}{C_o\,C_1}\,(C_2C_1+C_1C'+C_2C')\,\beta^2}. \tag{44}$$

The above equation may be put in the following form:

$$\alpha = \frac{L\,C\,R_o\,\beta^2\,(1+K_1) + L\,C\,R_2\,\beta^2\,\frac{C'\,C_2}{K_2\,C_o\,C_1}\,(1+K_1) - R_2\left\{(C_2+C')\left(\frac{1}{C_o}+\frac{1}{C_1}\right)+\frac{C'\,C_2}{C_1\,C_o}\right\} - R_o\left(1+\frac{C'}{C_1}\right)}{2\,L_2\left\{(C_2+C')\left(\frac{1}{C_o}+\frac{1}{C_1}\right)+\frac{C_2\,C'}{C_1\,C_o}+C_2\left(\frac{1}{C_1}+\frac{1}{C_o}\right)\left(1+\frac{C'}{C_1}\right)\right\} - 4\,L^2\,C^2\,\beta^2\,\frac{C'\,(1+K_1)}{K_2\,C_o\,C_1}}. \tag{45}$$

Putting

$$\frac{1}{C_a} = \frac{1}{C_o} + \frac{1}{C_o},$$

where C_a is the series antenna capacity, equation (45) reduces to

$$\alpha = \frac{L\,C\,\beta^2\,(1+K_1)\left(R_o + R_2\,\frac{C_2}{C_a}\right) - R_2\left(\frac{C_2+C_1}{C_a}+\frac{C'\,C_2}{C_1\,C_o}\right) - R_o\left(1+\frac{C'}{C_1}\right)}{2\,L_2\left\{\frac{2\,C_2+C'}{C_a}+\frac{C_2\,C'}{C_1\,C_o}+\frac{C_2\,C'}{C_1\,C_a}\right\} - 4\,L^2\,\frac{C^2}{C_a}\,\beta^2\,(1+K_1)}. \tag{46}$$

Introducing the values of β^2 as given by equation (42),

$$\beta_1^2 = \frac{1}{L\,C},$$

$$\beta_2^2 = \frac{1}{L\,C}\,\frac{1+K_2}{1+K_1},$$

and performing the various algebraic transformations, we arrive at the following formula for the damping factors:

$$\left.\begin{aligned}
\alpha_1 &= -\frac{R_o + R_2 \dfrac{C_2^2}{C_1^2}}{2\,L_2\left(\dfrac{C_2^2}{C_1^2} + \dfrac{C_2}{C_a}\right)}.\\
\alpha_2 &= -\frac{R_o \dfrac{C'}{C_1}\left(1 - \dfrac{C_a}{C_o}\right) + R_2 \dfrac{C'}{C_a}}{2\,L_2\left\{\dfrac{C'}{C_a} + \dfrac{C'C_2}{C_1^2}\right\}}.
\end{aligned}\right\} \qquad (47)$$

SUMMARY: The general theory of coupled radio frequency circuits is developed, for systems having two degrees of freedom, and for the resonance and non-resonance conditions. The theory is applied to determine the frequencies and damping factors for inductively coupled, directly coupled, and electrostatically coupled circuits.

DIGEST OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

GRANTED JANUARY 4, 1921–FEBRUARY 15, 1921

BY

JOHN B. BRADY

(OURAY BUILDING, WASHINGTON, D. C.)

The object of this section of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS is to make available in convenient form for research engineers and others interested, brief information on the radio patents which are granted each week by the Patent Office. The rapid developments in this art emphasize the importance of radio research engineers being familiar with patent literature in order to eliminate as far as possible the duplication of research effort. It is not the purpose of this section to explain radio inventions fully, but merely to indicate the general nature of the patents in order that those of particular interest to individuals concerned with current problems may be selected, and copies of the patents obtained for complete study. Copies of the complete patents may be obtained at ten cents each by addressing the Commissioner of Patents at Washington, D. C.

1,364,495—Henry Joseph Round, of London, and William Theodore Ditchman, of Twichenham, England, Assignors to Radio Corporation of America, of New York, N. Y., a corporation of Delaware.

Wireless Telegraph-Transmitter—Patented January 4, 1921.

This invention shows a circuit wherein current from an alternating source M is rectified and then smoothed out by a condenser L and utilized as a source of direct current for a valve oscillator. In the diagram, the grids of the tubes V and V' are connected to the armatures of two relays C and C' arranged in circuit with a key K, the opening and closing of which causes the energization of the relays, whereby the grids of the two tubes are simultaneously connected to corresponding ends of batteries *B B'* and are thereby made positive and negative with respect to the filaments whereby the circuits on the two sides of condenser *L* are opened and closed.

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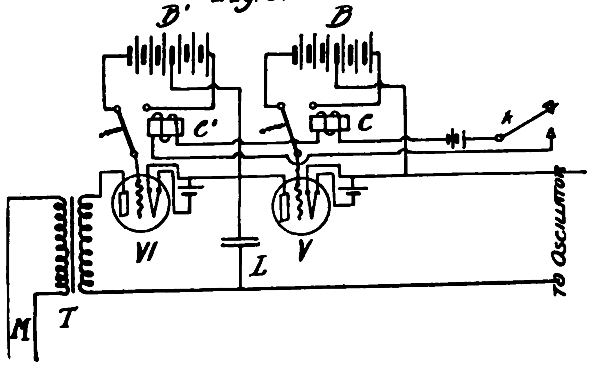
*Received by the Editor, March 3, 1921. While great care has been taken in the preparation of these Digests, THE INSTITUTE OF RADIO ENGINEERS assumes no responsibility for their correctness or completeness, or for possible omissions of particular patents.—EDITOR.

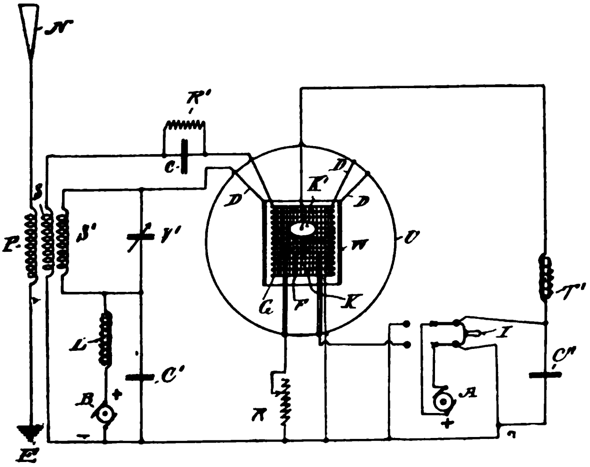
Fig. 3.



Number 1,364,495—Wireless Telegraph Transmitter

1,365,157—Lee de Forest, of New York, N. Y., Assignor to de Forest Radio Telephone and Telegraph Company, of New York., a corporation of Delaware.

Apparatus for Use in Telegraphy or Telephony—Patented January 11, 1921.



Number 1,365,157—Apparatus for Use in Telegraphy or Telephony

This invention pertains to a construction of audion in which an electric arc replaces the usual filament electrode.

1,365,292—Philip Thomas, of Edgewood Park, Pennsylvania, Assignor to Westinghouse Electric and Manufacturing Co., a corporation of Pennsylvania.

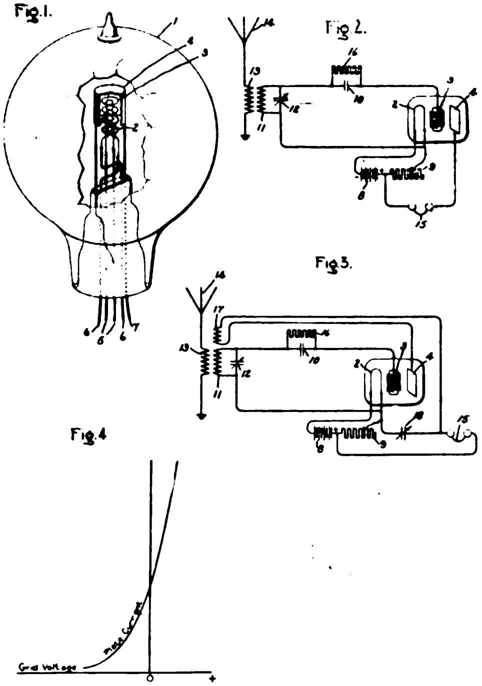
Method of Making Condensers—Patented January, 11, 1921.

This patent covers a method of impregnating condensers. The process comprises immersing the condensers in a solution of benzol and Montan wax, removing them after impregnation, immersing the condensers in a bath of commercially pure Montan wax at about 160 degrees C., then removing the condensers, and subjecting them to pressure in a cold press.

☛

1,365,576—William C. White, of Schenectady, New York, Assignor to General Electric Company, a corporation of New York.

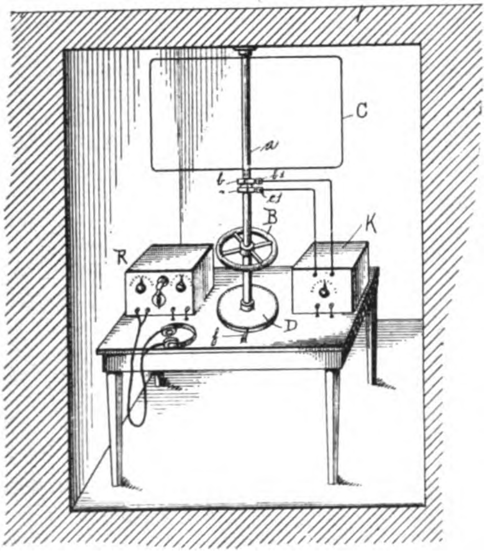
Radio-receiving System—Patented January 11, 1921.



Number 1,365,576—Radio-Receiving System

This patent shows an electron discharge tube for which a single battery is employed to function as a supply for the cathode anode circuit, the filament heating source, and also as a source between the cathode and grid for adjusting the normal potential of the grid. The construction of the tube is such that the cathode and grid are separated by as small a distance as possible and the anode spaced from the grid by a distance which may be slightly greater than the spacing between cathode and grid but which will in any case be very small.

1,365,579—Thomas Appleby and Lloyd M. Knoll, of Philadelphia, Pennsylvania, Assignors of one-third to Cornelius D. Ehret, of Philadelphia, Pennsylvania.
Radio apparatus—Patented January 11, 1921.

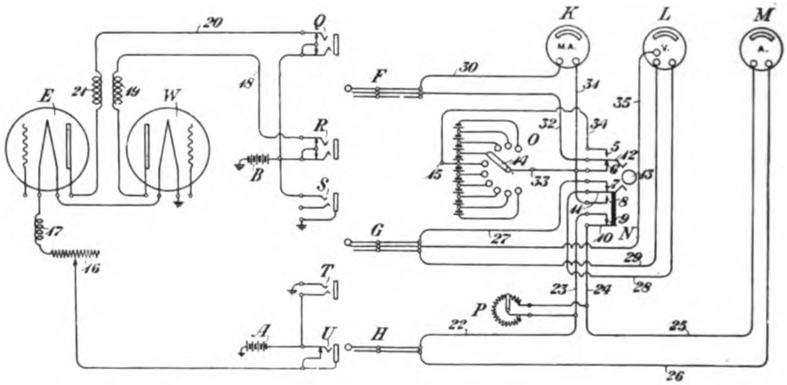


NUMBER 1,365,579—Radio Apparatus

This patent shows a rotary loop antenna arranged underground and shielded to reduce distortional effects. Other figures of the patent show arrangements of shielded loops for multiplex operation.

1,365,734—Samuel P. Shackleton, of New York, N. Y., Assignor to American Telephone and Telegraph Company, a corporation of New York.

Electron-Tube-Testing Circuits—Patented January 18, 1921.



NUMBER 1,365,734—Electron-Tube-Testing Circuits

This patent pertains to a testing apparatus for vacuum tubes to determine expeditiously whether or not the tube is operating within certain prescribed limits.

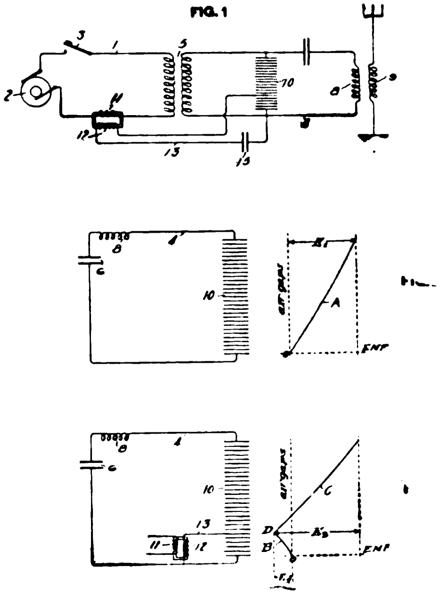
1,365,787—Fred H. Kroger, of Brooklyn, New York, Assignor by Mesne Assignments, to International Radio Telegraph Company, a corporation of Delaware.

Method and Apparatus for Wireless Signaling—Patented January 18, 1921.

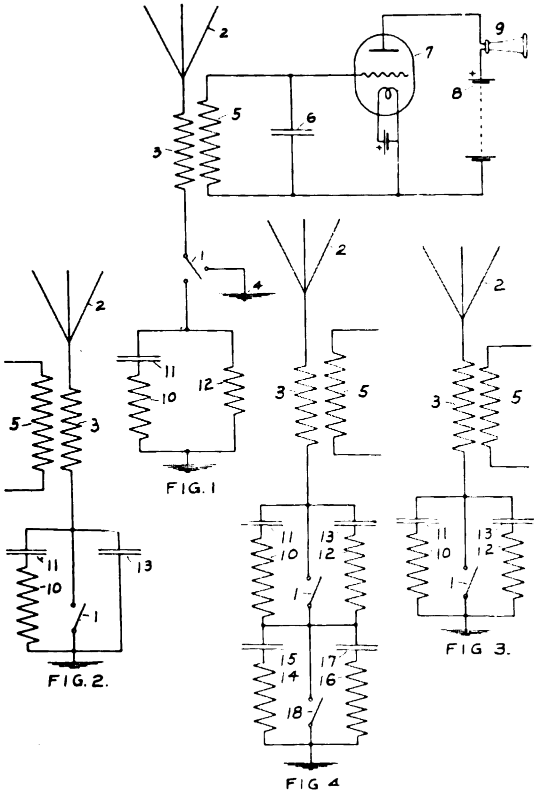
The object of this invention is to secure a more perfect tone control of a quenched gap transmitter. The transmitter circuit is arranged as shown in the diagram with a step-up transformer having its primary winding 11 in the power circuits and its secondary 12 in a control circuit 13 connected across part of the gap. The function of the auxiliary circuit is to impress on the gap an audio frequency impulse at a definite instant in each half cycle of the normal voltage whereby the gap breaks down at regular intervals.

1,365,926—Tyng M. Libby, of Tacoma, Washington, Assignor to Henry G. Cordes, of Bremertown, Washington.

Radio Interference Preventer—Patented January 18, 1921.



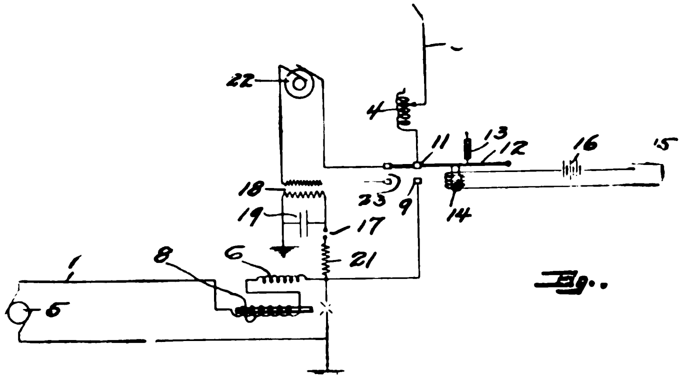
Number 1,365,787—Method and Apparatus for Wireless Signaling



Number 1,365,926—Radio Interference Preventer

This invention relates to a receiving circuit so arranged that interfering signals can be counteracted and signals of a desired frequency received.

1,365,977—Leonard F. Fuller, of San Francisco, California, Assignor, by Mesne Assignments, to the United States of America.
Radiotelegraphy—Patented January 18, 1921.



NUMBER 1,365,977—Radiotelegraphy

This patent relates to an arc signaling system. The antenna circuit is opened and closed in accordance with signal characters to be transmitted. The arc is extinguished each time that the antenna circuit is opened, but re-ignited upon the closing of the antenna circuit by energy from an auxiliary source 22.

1,366,160—August J. Kloneck, of New York, N.Y.
Rotary Spark-Gap—Patented January 18, 1921.

This patent concerns a particular circuit arrangement for a rotary spark-gap radio transmitter.

1,366,311—Fulton Cutting, of Tuxedo Park, New York, and Bowden Washington, of Cambridge, Massachusetts.
Production of High-Frequency Oscillations—Patented January 18, 1921.

Fig. 1.

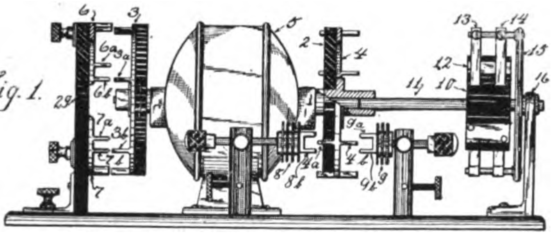
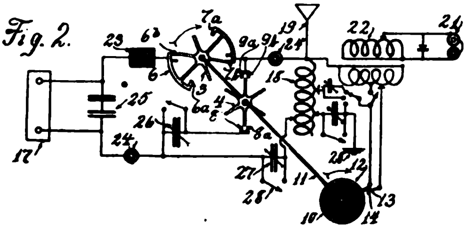


Fig. 2.



Number 1,366,160—Rotary Spark-Gap

Fig. 1.

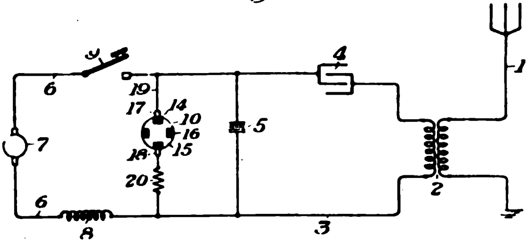
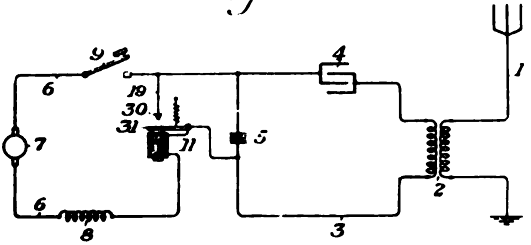


Fig. 2.



Number 1,366,311—Production of High-Frequency Oscillations

This patent relates to the production of high frequency oscillations by periodically exciting a discharge gap and condenser circuit so as to produce groups of radio frequency oscillations. The circuit includes a condenser, a supply circuit, a discharge gap for the condenser, of for example the Chaffee type, and a make and break which operates at an audible frequency when the oscillations are being produced to short circuit the gap periodically, whereby the radio frequency oscillations have a group frequency corresponding to that of the make and break device.

1,366,411—Alexander McLean Nicolson, of New York, N. Y., Assignor to Western Electric Comapny, Incorporated, of New York, N. Y., a corporation of New York.
Thermionic Translating Device—Patented January 25, 1921

Fig. 1

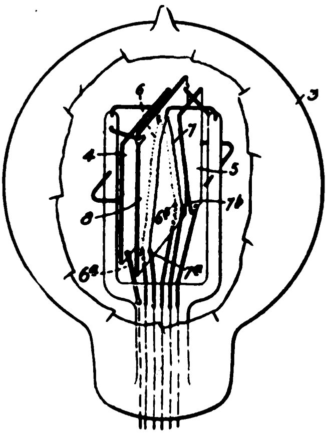
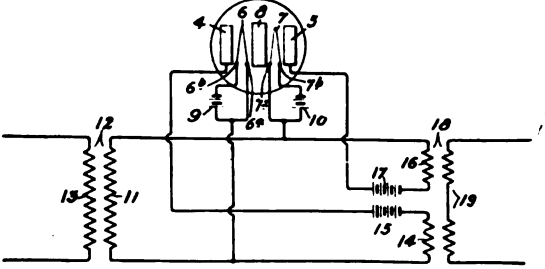


Fig. 2.

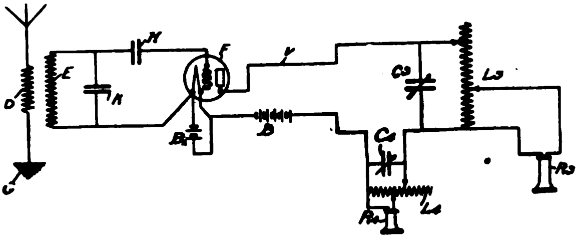


NUMBER 1,366,411—Thermionic Translating Device

This patent shows a vacuum tube comprising two cathodes. a dielectric sheet of mica separating the cathodes and an anode, adjacent to each of the cathodes. The tube is arranged in circuit in such manner that one cathode always serves as a control electrode for the electron flow from the other cathode.

1,366,830—Frederick E. Pernot, of Berkeley, California, Assignor of one-third to George Lothaine Greves, of Berkeley, California.

Frequency-Selecting Receiving-Circuit—Patented January 25, 1921.



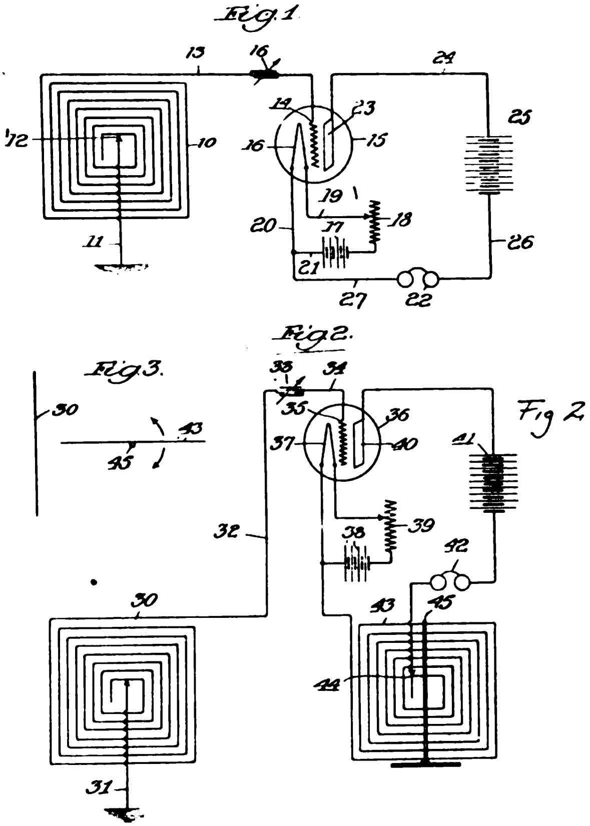
Number 1,366,830—Frequency-Selecting Receiving Circuit

This invention relates to a receiving circuit arranged to segregate and respond simultaneously to separate signal impulses of different group frequencies. The circuit is shown in the accompanying diagram wherein two operators receive simultaneously signals of different group frequencies, one by means of circuit $C_3L_3R_3$ and the other by aid of circuit $C_4L_4R_4$. Each receiver circuit is sensitive to one group frequency only.

1,366,953—Henry K. Sandell, of Chicago, Illinois, Assignor to Herbert S. Mills, of Chicago, Illinois.

Radio Receiving Apparatus—Patented February 1, 1921.

A form of receiving circuit is shown in this patent. A grounded loop antenna 30 is employed connected at the other end with the grid of a vacuum tube. In another form a second loop antenna in proximity to the first grounded antenna is connected in the plate circuit and arranged for angular adjustment relative to the first loop.

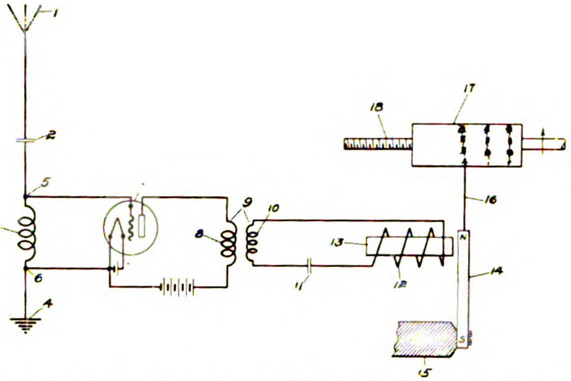


Number 1,366,953—Radio-Receiving Apparatus

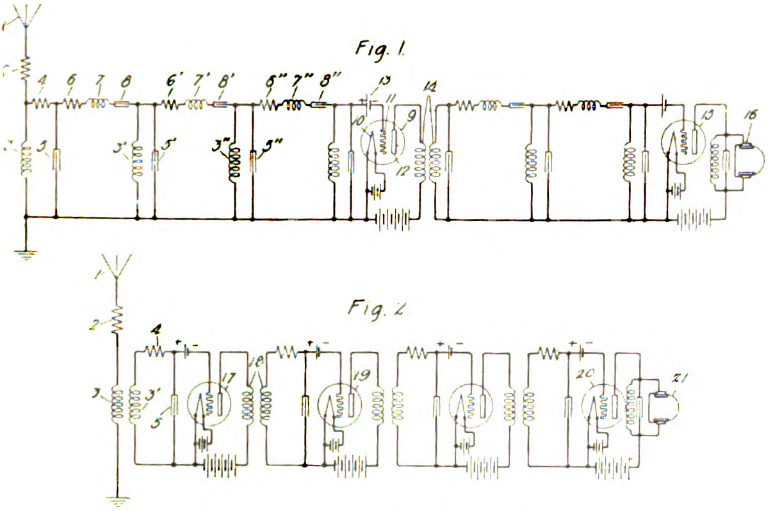
1,367,165—Haraden Pratt, of San Francisco, California. Radio Telegraphic Receiving System—Patented February 1, 1921.

This patentee claims a receiving system having a tuned circuit containing an electromagnet with armature mechanically tuned and adapted to vibrate in synchronism with the radio frequency energy received by the antenna system. The armature is shown associated with tracing arm of an inking recorder.

1,367,224—Harold de Forest Arnold, of East Orange, New Jersey, Assignor to Western Electric Company, Incorporated, of New York, N. Y., a corporation of New York. Radio-Receiving System—Patented February 1, 1921.



Number 1,367,165—Radio Telegraphic Receiving System



Number 1,367,224—Radio-Receiving System

This invention pertains to a highly damped receiving circuit selectively responsive to signal oscillations of a given frequency. The curcuit includes an antenna system, and a chain of resonant circuits coupled to the antenna, each circuit of the chain being rendered aperiodic by damping.

1,368,584—Samuel S. Torrisi, of Philadelphia, Pennsylvania.
Cathode for Audions—Patented February 15, 1921.

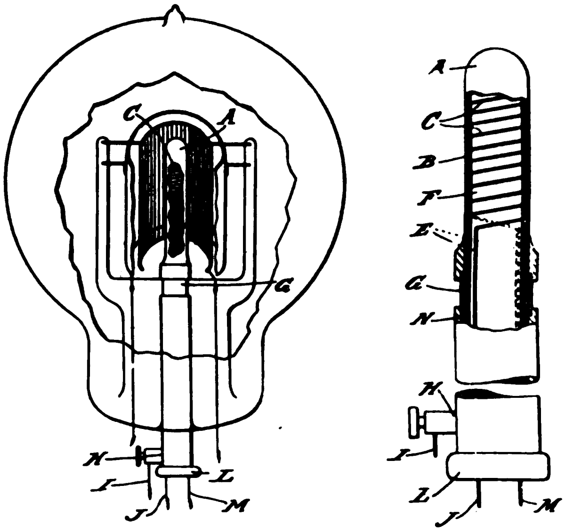


Fig. 1

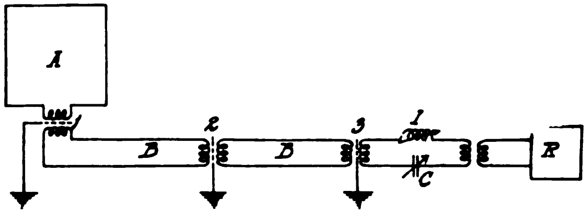
Fig. 2

Number 1,368,584—Cathode for Audions

This patent shows a construction of vacuum tube designed to eliminate the filamentary cathode. The cathode is formed of a heating coil wound upon a removable rod and enclosed within a cathode tube which forms the electron emitting element.

1,368,622—Charles Samuel Franklin, of Buckhurst Hill, England, Assignor to Radio Corporation of America, a corporation of Delaware.

Aerial System Employed in Wireless Telegraphy and Telephony—Patented February 15, 1921.

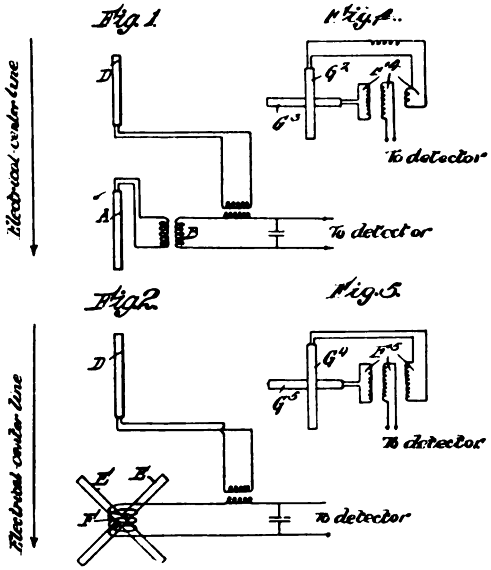


Number 1,368,622—Aerial System Employed in Wireless Telegraphy and Telephony

This invention pertains to a system for loop radio reception.

1,368,657—Henry Joseph Round, of Muswell Hill, London, England, Assignor to Radio Corporation of America, of New York, N. Y., a corporation of Delaware.

Wireless Direction-Finder—Patented February 15, 1921.



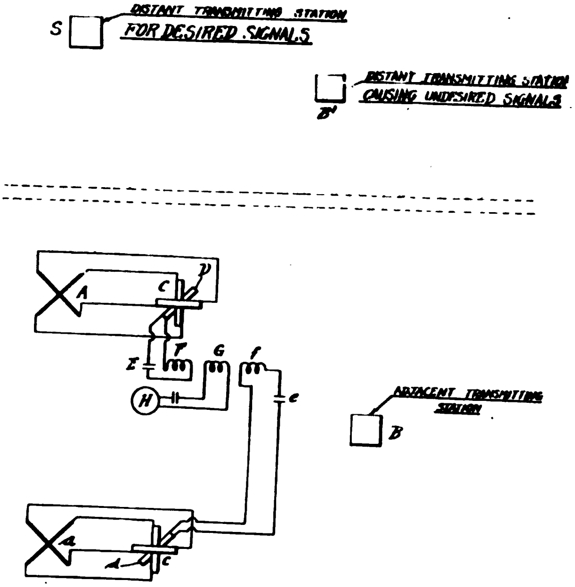
Number 1,368,657—Wireless Direction-Finder

This invention relates to the reduction of error in direction-finder readings where the receiving direction-finder antenna is surrounded by interfering metallic structures such as parts of a ship or aeroplane. The effect of these structures is compensated to give the true direction of signals.

Reissue 15,040—Charles S. Franklin, of London, England, Assignor, by Mesne Assignments, to Radio Corporation of America, a corporation of Delaware.

Aerial Conductor for Wireless Telegraphy—Reissued February 15, 1921.

This patent relates to a reciving circuit for duplex operation in conjunction with an adjacent transmitter. The circuits are based on the principle that antennas of two loops placed at right angles to each other and used in connection with a radio-goniometer can receive best from any two opposite directions and eliminate signals from any two opposite directions at right angles to the first.

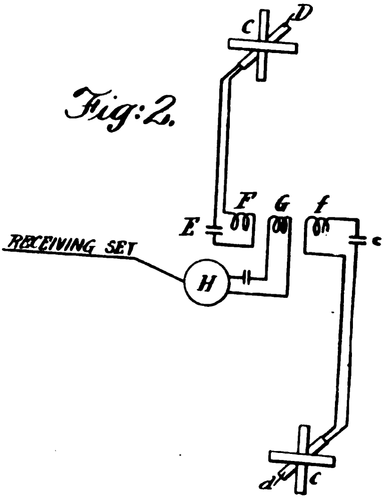

DISTANT TRANSMITTING STATION
FOR DESIRED SIGNALS
S
DISTANT TRANSMITTING STATION
CAUSING UNDESIRED SIGNALS
B'
A
C
D
E
F
G
f
H
e
ADJACENT TRANSMITTING STATION
B
A
d
c

Reissue Number 15,040—Aerial Conductor for Wireless Telegraphy

Reissue 15,041—Charles S. Franklin, of London, England. Assignor, by Mesne Assignments, to Radio Corporation of America, a corporation of Delaware.

Aerial Conductor for Wireless Telegraphy—Reissued February 15, 1921.

Fig:2.



Reissue Number 15,041—Aerial Conductor for Wireless Telegraphy

This patent relates to an antenna system for a receiving station adapted to operate in conjunction with an adjacent transmitting station for duplex radio telegraphy.

PROCEEDINGS OF
The Institute of Radio Engineers

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The College of the City of New York
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AMENDMENTS TO THE CONSTITUTION OF THE INSTITUTE OF RADIO ENGINEERS

The following amendments to the Constitution of the Institute were submitted to the membership for vote, in accordance with the procedure set forth in the Constitution. Having been adopted by the membership by the vote given in each case below the text of the amendment, they are now a portion of the Constitution of the Institute. The attention of the membership is accordingly directed to their text, as here given.

ARTICLE VII

SECTION 1: Six weeks before the annual meeting, the Board of Direction shall submit to the entire membership, excepting Honorary Members and Juniors, a list of candidates (nominees) for the offices of President, Vice-President and two Managers. This list shall comprise at least two names for each office, the names being proposed either by Petition as hereinafter provided, or by a majority of a quorum of the Board of Direction, at one of its stated meetings. The list shall contain no indication as to whether the candidate has been proposed by Petition or by the Board of Direction.

Nomination by Petition shall be made by letter, addressed to the Board of Direction, setting forth the name of the proposed candidate and the office for which it is desired he be nominated. For acquiescence a letter of Petition must reach the Board of Direction on or before October 1st of any year, and shall be signed by at least thirty-five Fellows, Members or Associates in good standing.

The list of nominees shall contain the names of all candidates proposed by formal Petition or by the Board of Direction, but before this list is submitted to the membership for final vote, each candidate shall be consulted and if he so requests, the fact that he has withdrawn from the election shall be stated after his name.

The entire membership in good standing, excepting Honorary Members and Juniors, shall be eligible to vote by written ballots in plain sealed envelopes, enclosed within mailing envelopes marked "Ballot" and bearing the member's signature for the officers whose names appear on the list of candidates. A majority vote received up to the time of the closing of the polls (twenty-four hours before the opening of the annual meeting, the date of which shall be stated in the election notice) shall elect, and no votes by proxy shall be counted. No proxies or ballots within unsigned outer envelopes shall be opened for counting. Ballots shall be checked, opened, and counted by a quorum of the Board of Direction, at a meeting of the Board.

The above amendment was adopted by an affirmative vote of 479 to 8.

SECTION 2: The Treasurer, Secretary, and Editor of Publications shall be appointed by majority vote of a quorum of the entire Board of Direction as soon as practicable after January 15th of each year, for a term of at least one year or until their successors be appointed.

The above amendment was adopted by an affirmative vote of 465 to 22.

RECENT PROGRESS IN RADIO COMMUNICATION IN GERMANY AND AUSTRIA*

BY
DR. EUGEN NESPER
(VIENNA, AUSTRIA)

The radio work of the last years of the World War and of the period immediately following (which has been one of unfortunate scientific depression for the Central European Powers) has been concentrated on vacuum tube transmitters, amplifiers, receivers, and auxiliary beat or heterodyne receiving apparatus. Many different lines of development have been required to meet the very special demands of fixed stations, heavy mobile stations, easily portable stations, and ship and aircraft stations. Reception with a coil or loop antenna provided with a radio frequency amplifier-detector-audio frequency amplifier for the reception of broadcast press messages and of financial and weather reports has found a previously unexpected vogue and usefulness. This mode of receiving without an elevated antenna or ground connection is based on the development of the amplifier which originated in the United States (Lee de Forest). Furthermore, the normal specifications for the construction of stations and equipment in the various countries differed more or less. Considering the then available personnel, it was found, for example, in Germany, that obviously more difficult requirements had to be met in the apparatus than in the same or at least similar English apparatus.

A number of typical instances will be given to show the practical application of the above considerations to the most recently developed equipment.

As a first example, there will be considered a vacuum tube transmitting and receiving set constructed by the C. Lorenz Company, of Berlin. The actual set is illustrated in Figure 1. It can be used for ordinary radio telegraphic transmission, for measurements of wave length in searching for the signals of distant transmitters, for reception with primary circuit only, for reception using a secondary circuit, and for radio telephony. This apparatus, therefore, is adapted to a variety of uses, and yet covers a relatively wide range of wave lengths, namely from 350 to 1,800 meters, and for both the primary and secondary circuits. By turning the main control handle *a*, the set can be

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* Received by the Editor, July 6, 1920. Presented before THE INSTITUTE OF RADIO ENGINEERS, New York, September 1, 1921. Translated from the German by the Editor.

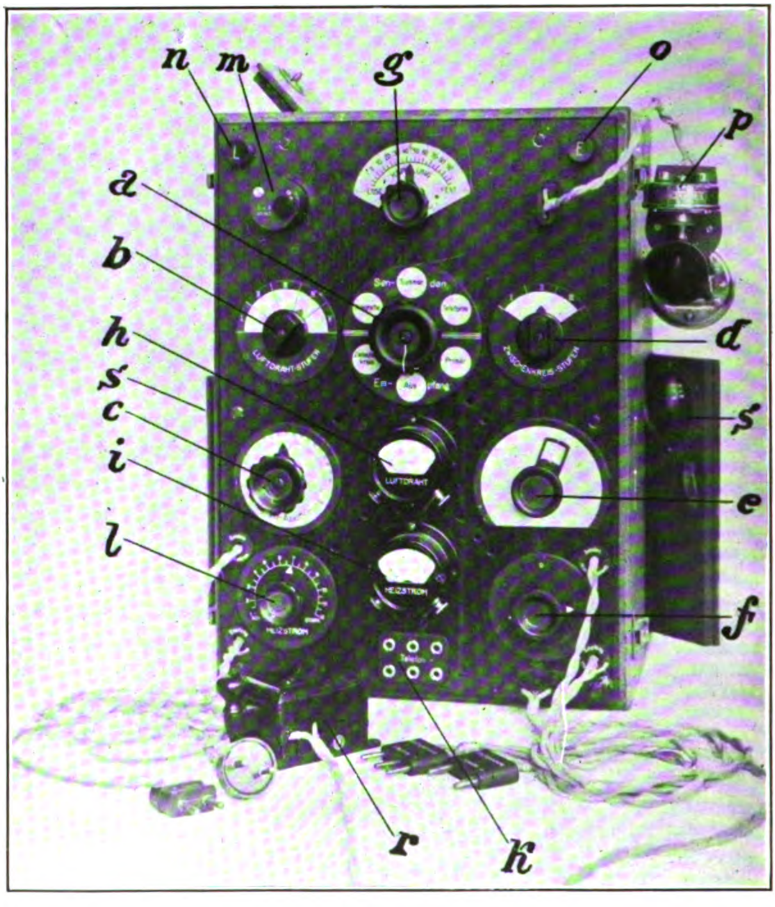

FIGURE 1

readily used in any of the ways indicated above. For operating the apparatus, a number of handles project from the front panel, each handle being provided with a pointer or a window indicator. These pointers or indicators move over appropriate scales graduated in degrees, wave lengths, closeness of coupling, or filament heating current. The upper handles on the left side of the panel control the antenna inductance and the antenna condenser, the handle *b* controlling the steps of antenna inductance and the handle *c* the antenna condenser. The secondary circuit is controlled by handles on the right side of the panel, thus *d* controls the steps of secondary inductance, *e* the main secondary condenser, and *f* a small condenser in parallel with the main secondary condenser and intended for fine tuning when employing beat reception. The handle controlling the coupling between the antenna and secondary circuits *g* is mounted at the middle top of the panel. In addition, the panel carries a small antenna ammeter *h* under which is placed a second ammeter *i* for filament current. Under this latter are jacks *k* for plugging in three telephone receivers or, if desired, a suitable amplifier. In the lower left-hand corner of the panel is the handle *l* which controls the filament current of both the transmitting and the receiving tubes. The buzzer *m* is mounted on the upper portion of the panel, and the antenna and ground connections *n* and *o* are brought to the binding posts at the upper corners of the panel.

A telephone transmitter *p*, adjustable so as to fit the head of the operator, is provided, and can be plugged into the side of the case. The key *r* is similarly provided with cords and a plug so that it can be connected thru the jack at the bottom of the panel.

Small doors *s* are fitted into each side of the case. Mirrors on the inside of these doors enable the operator to see both the transmitting and receiving tubes in the inside of the case, and to note if the filaments burn out. The location of the bulbs in the interior of the case is advantageous in that it keeps the insulation warm and dry, and therefore, in good condition. This is important when the set is used in damp locations.

In the left-hand portion of Figure 2 is shown the transmitting circuit. The transmitting tube *t* is lit by a 12-volt storage battery. Plate voltage is provided either by a 500-volt dry battery assembly *u* or by a small direct current generator. A large condenser is shunted across *u*. The key is *r*, and *d* is the stepwise variable secondary coil. The secondary tuning condenser is *e*. A fixed mica condenser *v* can be connected in parallel to *e*, this being done automatically by the inductance step-control switch *d* of Figure 1. The condenser *w* is the substitute and equivalent of the "tone condenser" *f* (to be described below), and is automatically connected into circuit when changing over from receiving to sending by means of the main control switch *a*.

The internal capacity of the tubes is compensated for by the equivalent capacity of the condenser *x* which is automatically inserted into the circuit across coil *d* when the control switch *a* is thrown over from transmitting to receiving. It should be noted at this point that the secondary coil *d* is used for both transmission and reception, and hence the necessity for the various substitute condensers *w* and *x*.

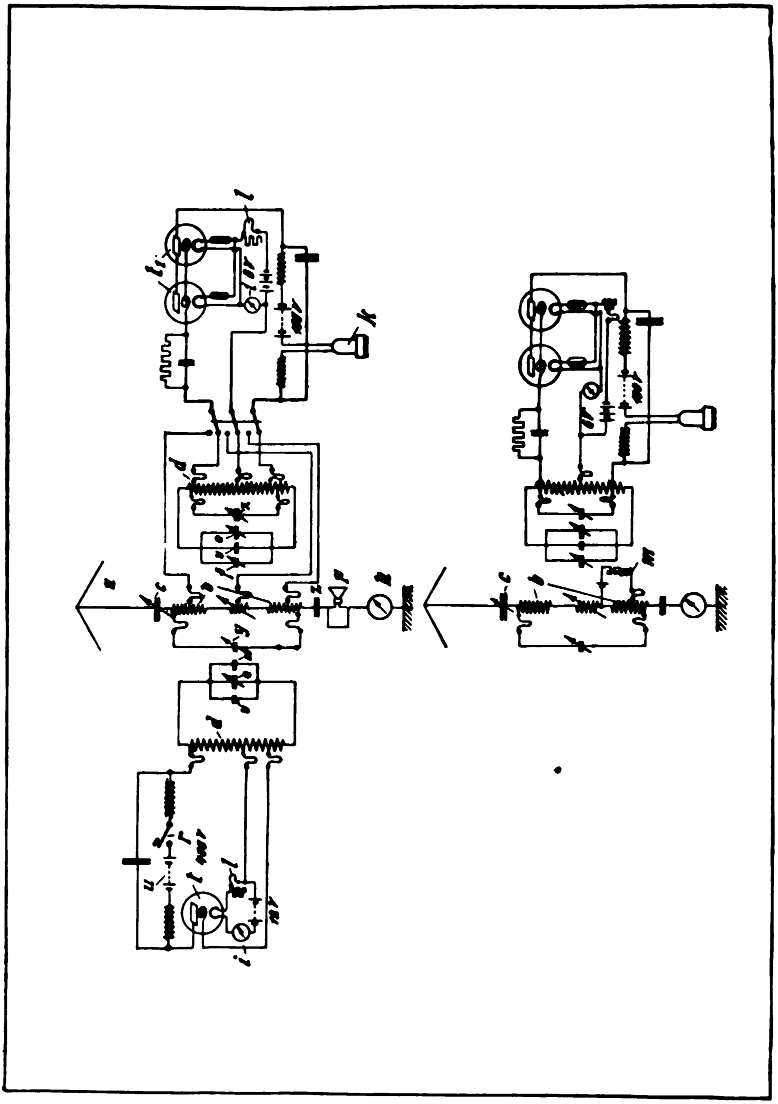

FIGURE 2

The antenna inductance *b* (which is stepwise variable) and the antenna tuning condenser *c* form the main elements of the antenna circuit. In parallel with coil *b* is connected the condenser *y* when sending or receiving with the secondary circuit in use. Condenser *y* compensates for the tube capacity. It is automatically inserted by switch *a*. Transmission using a primary or antenna oscillating circuit alone is not used, because too large a proportion of overtones would be radiated. There are also inserted into the antenna a fixed capacity *z*, the ammeter *h*, and, when required for telephony, the microphone transmitter *p*.

The circuits for reception with the primary alone and also using the secondary as well are shown in the right-hand portion of Figure 2. The receiving tubes t_1 can be directly connected to the antenna circuit *n c b z h*, and the beat reception employed. A filament voltage of 6 and a plate voltage of 100 are then used. The telephone receiver *k* is connected in series with the plate battery.

In changing over from primary circuit reception to secondary circuit reception, the condenser *y*, which is connected at one terminal only to the coil *h* during primary circuit reception, is then shunted across coil *h*, and the secondary coil *d* is inductively coupled to the antenna circuit. The secondary circuit consists of coil *d* and the variable condenser *e*, in parallel with which latter an extra fixed condenser *v* and a "tone condenser" *f* are connected. The beat note is regulated by means of the tone condenser, which is, therefore, a relatively small capacity. The substitute condenser *x* is also connected in circuit in this case. In searching for the signal of a distant continuous wave station, the following procedure is carried out. The main switch *a* is set to primary circuit reception. By varying the inductance step switch *b* and the variable condenser *e*, the beat tone which indicates the approximate setting is obtained. After accurately securing the desired note, the operator switches over to reception with the secondary circuit connection, first setting the handle of the tone condenser *f* to the zero position (neutral zone). By variation of the step control switch *d* and careful adjustment of the secondary condenser *e*, the set is tuned to a resonance maximum. The desired tone is then obtained by adjusting the tone condenser *f*. The coupling between primary and secondary *g* is then adjusted for the loudest signal. In case the transmitting and receiving wave lengths are equal, the operation of the set becomes especially simple. It is then necessary merely to throw the main switch *a* from the "secondary reception" position to the immediately adjoining transmitting position. By operation of the key, and noting from the antenna ammeter *h* that normal radiation is being secured, the transmission may then proceed without any further adjustment.

The measurement of wave length is accomplished as indicated in the lower diagram of Figure 2. The buzzer *m* is started by throwing the main switch *a* into the corresponding position. This sets the antenna into oscillation at the desired wave length provided the inductance *b* and the condenser *c* are adjusted until the secondary circuit indicates resonance. The secondary condenser then gives the wave length of the received signal.

In addition to the typical set just described, vacuum tube transmitters up to a 10-killowatt size have been built in a wide variety of forms. From these numerous types, one built by the former Lorenz Company of Vienna is chosen as an illustration of convenient portability and carefully chosen electrical design. Furthermore this set is intended for transmission and reception on unusually short wave lengths, namely 50, 60, 70, 80, 90, and 100 meters. In Figure 3, this set is shown with the cover of the cabinet removed. For transmission, a larger type of tube (which is behind the window at the right, but is not visible in

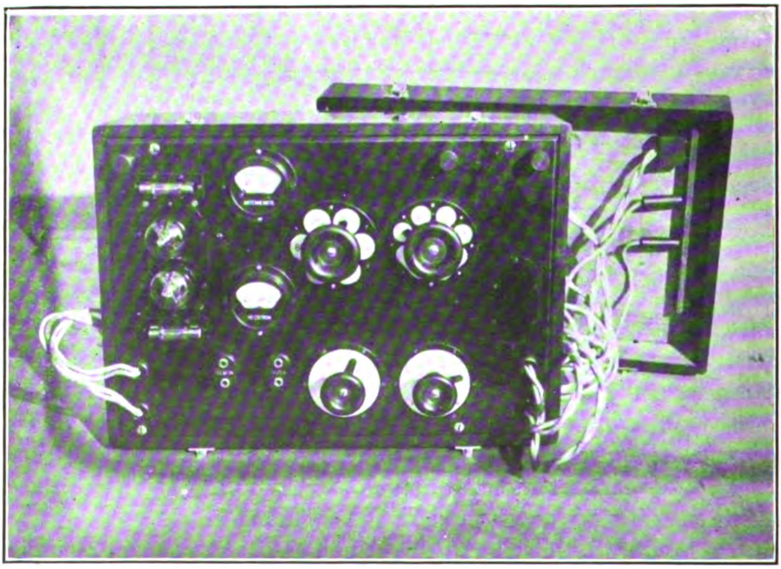

FIGURE 3

the illustration) is employed; while two small bulbs are used for reception to ensure reliable beat reception particularly at such short wave lengths. The set is so constructed that it is largely independent of the size and type of antenna between wide limits. This is arranged for by providing a variometer adjustment for maximum antenna current, in addition to the stepwise adjustment of antenna inductance.

Both transmitting and receiving tubes are arranged so as to heat the interior of the apparatus (thus minimizing the effect of moisture on the insulation), and are also placed so that their light is available for writing or reading messages. The antenna and ground are connected to the right-hand binding posts. The control handle underneath them provides for changing from sending to receiving. In addition, this handle can be set to "Off," or to a position in which the transmitting tubes are not burning at full brilliancy. The adjoining handle controls the switch whereby any of the six fixed wave lengths can be chosen. Thereafter maximum antenna current is secured by adjustment of the variometer in the antenna circuit. The handle of this variometer is at the bottom right. To its left is the control handle for varying the note in beat reception. The two jack pairs at the left are for the insertion of plugs connected to the telephone receiver and the key. The twin-conductors serve for connection to the filament and plate batteries, those at the left being for the receiving tubes and those at the right for the transmitting tubes.

The apparatus next to be described is intended either for receiving purposes or for making radio measurements.

The very great importance of amplification in radio reception has been recognized for many years. As a result a considerable number of mechanical amplifiers have been devised, which however, proved to be unpleasantly sensitive to vibration, shocks, and mechanical injury. It remained for a number of investigators, particularly in America with (Lee de Forest as the pioneer) to meet the needs of the situation by the use of vacuum tubes. Practical tubes of this type were produced by Irving Langmuir and others, and they were found to be very satisfactory amplifiers since they were practically uninfluenced by mechanical disturbances and, being almost instantly responsive in their action, permitted radio frequency amplification as well as audio frequency amplification.

Taking an audio frequency amplifier first, the physical phenomena will be explained in connection with Figure 4. Radio [illegible] amplification will be considered in connection with the use of [illegible].

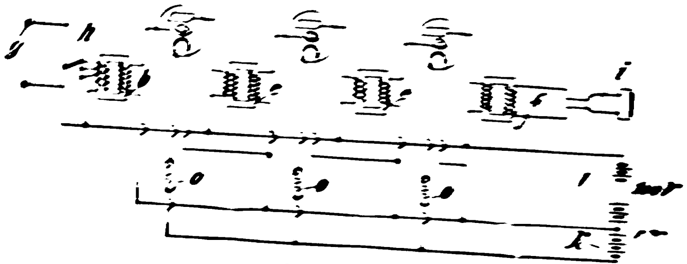

FIGURE 4

The energy which is to be amplified, for example, that received from the detector, is led to the terminals *g* of the amplifier, and then thru a small iron core transformer *h b* to the grid circuit of the first tube. The function of the amplifier is to obtain as high a potential variation as possible on this grid. Since various forms of detector supply their output energy at different voltages, the primary *h* of the transformer is sometimes provided with three taps controlled by a suitable switch. In general, however, a fixed primary is provided and the switch eliminated. An energy amplification of the order of ten times is obtained in the plate circuit of the first bulb, the energy being supplied by the plate battery *l*.

A second transformer is inserted in the plate circuit of the first tube, and the secondary of this transformer is connected to the grid circuit of the second tube, which, since it produces a ten-fold energy amplification, has an energy output one-hundred times the original input (approximately). The same effects are produced by the third tube, so that a total amplification of energy of the order of a thousand times is to be expected. This is transferred by the step-down transformer *f* to the telephone receiver *i*.

The filaments of all the tubes are fed from the battery *k*, and the ballast resistances *o* (of iron in an atmosphere of hydrogen) in series with each tube serve to prevent excessive current thru their respective filaments.

An amplifier constructed on the basis of the preceding circuit by the former Lorenz Company of Vienna is shown in Figure 5. The three tubes are mounted on a horizontal panel in a wooden box with a swinging top. In front of the tubes are placed the iron-in-hydrogen ballast resistances which can be readily interchanged in view of the clip-contact mountings. The fine internal iron wires are at a dull red heat when they are functioning properly. On the front of the box may be seen two sliding doors which permit access to two switches. One of these has two positions: "On," meaning that the amplifier is in use, and "Off," meaning that the telephones are connected directly to the input or detector circuit without the interposition of the amplifier. At the left side of the box is a plug pair which permits connecting the amplifier to the energy input circuit. On the right side of the box, but not visible in the illustration, are two pairs of terminals, one for the 100-volt plate battery (usually of dry cells), and the

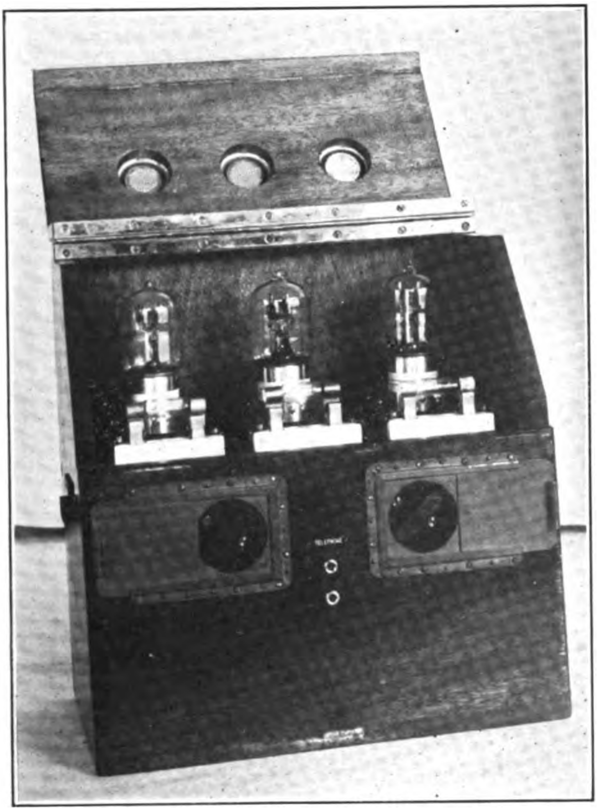

FIGURE 5

other for the 6-volt filament battery (usually a storage battery). When the amplifier is in use, the top of the box is generally closed, and the holes in the top permit the operator to note whether the bulbs are lit or not.

Probably the greatest changes in the radio field, at least as regards reception, have been brought about by the development of the amplifier. It has thus become possible to increase the strength of the received signals to almost any desired limit, and indeed to dispense with large elevated antennas and, even for reception from long distances, to accommodate loop antennas of convenient dimensions inside ordinary rooms.

The most common arrangement is given in the diagram of Figure 6. The loop antenna *a* consists of several turns of insulated copper wire which may be fastened to one wall of the receiving room. In other cases, when it is desired to vary the direction of best reception at will, the loop can be mounted on a light wooden frame which can be rotated and which may be suspended from the ceiling of the room or otherwise mounted.

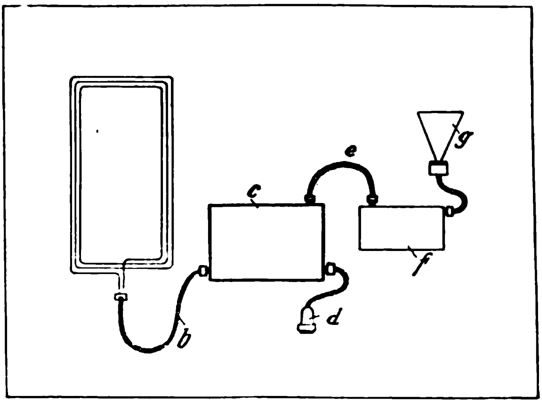

Figure 6

From the terminals of the loop antenna a twin conductors cord, terminated by appropriate plugs *b*, leads to the terminals of the special receiver *c*. The construction of this receiver is described below in connection with Figure 7 which shows a type built by the former J. Berliner Company of Vienna. By means of the loop receiver, naturally tuned to the appropriate wave length, and using the telephone *d*, reception from such distant stations as Paris, Lyons, Petrograd, or any other large stations in Europe, and sometimes even North America, can be accomplished.

In case, however, the loudness of signals thus obtained is not sufficient, or in case it is desired to obtain such loud signals that a large group of auditors can hear them, a further amplifier *f* is used which is connected by the conductors *e* and plugs to the receiver *c*. This particular amplifier feeds a loud-speaking receiver or "Megatelephone" *g*. If a large horn is used with this latter, the signals become easily audible thruout a large room. As an alternative, in place of the loud-speaking receiver *g*, an ordinary receiver may be used connected to the amplifier *f*. This is desirable when the received energy is very small, as in reception from very great distances or using very small loops.

The arrangement of the loop receiver shown in Figure 7 permits of obtaining very loud signals even without beat reception auxiliary apparatus (external heterodyne oscillator) or further amplifiers. In all, seven tubes are used, which can be seen in the middle of the apparatus. The circuits are so arranged that the first four tubes are used for radio frequency amplification, the fifth tube is used as a detector, and the last two tubes for audio frequency amplification.

The tuning elements, inductances and condensers, are built into the cabinet in this piece of apparatus. The inductances are mounted behind the glass-covered calibration chart at the right. The variable condenser is visible in the middle of the bottom. The wave length can be varied continuously between 200 and 24,000 meters. The stepwise regulation of the coils—there are three coils in all—is carried out by the control handle mounted directly over the variable condenser handle. The filament current can be read by means of the small ammeter to the left of the condenser handle. To the left of this are two more handles, the lower one of which controls the filament current rheostat, and the upper one of which enables turning the filament and plate currents on and off.

In the left bottom corner can be seen a small block carrying jacks for the insertion of two telephone receivers and also for the filament and plate batteries. The movable handle directly over this block serves to control a resistance inserted into the plate lead of the fourth tube ("regeneration control resistance"), thus obtaining beat reception in the upper portions of its range of motion and ordinary detection in the lower portions. The antenna is connected to the two binding posts in the upper right-hand portion of the case.

The coupling between each tube and the next consists of a high resistance, with the exception of the fifth and sixth tubes and the coupling to the telephone receiver. For the former cases step-up transformers are used; for the latter case a step-down transformer.

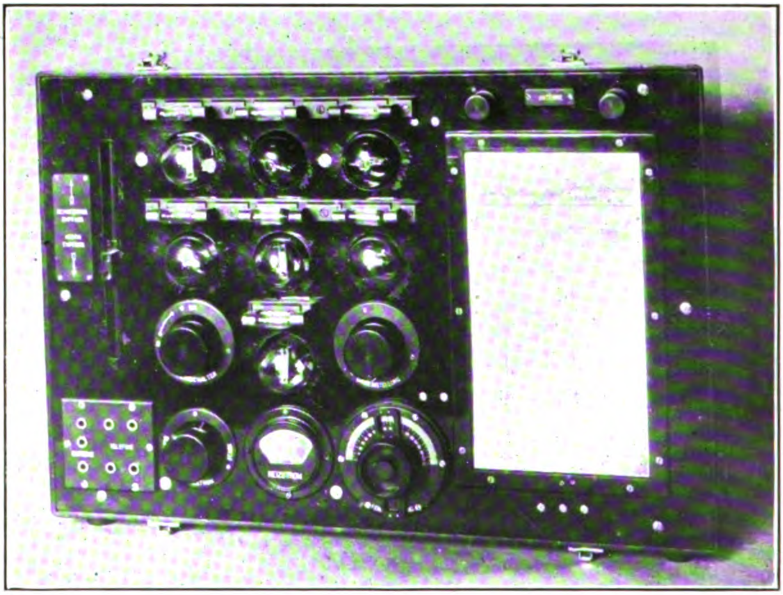

FIGURE 7

By thus combining radio and audio frequency amplification, the available sensitiveness of the apparatus is such that with a loop antenna of 30 turns and 1.5 square meters area (4 feet square) reception from America can sometimes be accomplished. However, it is generally advisable when working with such small loop dimensions to have an external heterodyne oscillator which may be coupled to the receiver in a variety of ways, and most simply by placing it in the neighborhood of the receiver.

The physical phenomena in this case are the following: A minute portion of the energy electromagnetically radiated from the distant station is received by the loop antenna *a* (Figure 8), and is carried by the conductors *b* to the tubes of the receiver *c*. The first three of the tubes in *c* act as pure radio frequency amplifiers so that the extraordinarily small input energy is markedly increased by them. The third tube output will accordingly represent about one thousand times the energy received by the loop *a*. This increased energy is then transferred to the fourth and fifth tubes, which partly produce further amplification, but at audio frequency, and partly produce so-called rectification which enables the incoming energy to actuate the telephones. It is also possible by adjustment of the regeneration control resistance to produce beat reception without additional apparatus, so that, when receiving continuous waves, a clear tone is heard in the telephones in correspondence with the Morse signals sent from the distant station. Since the amplitude of the local oscillations can be varied by means of this same resistance, it is possible to select the best ratio between the amplitude of the incoming signal current and the locally generated oscillating current, in this way securing a maximum signal strength on various wave lengths and for various intensities of the incoming signal. Above a certain value of the resistance, the local oscillations cease, and ordinary detector reception of damped waves becomes possible.

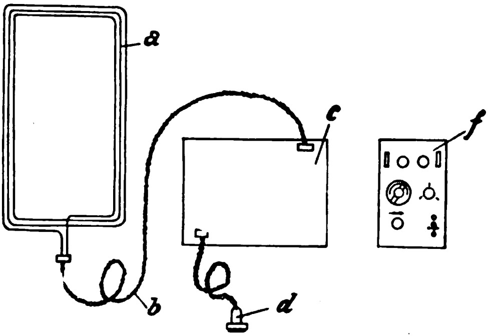

FIGURE 8

Loop antennas with such a receiver therefore constitute a complete substitute for:

1. The earlier types of complicated receivers with secondary circuit and many adjustments.
2. Former equipment for receiving press news, financial reports, and similar information in the long wave range from 2,500 to 20,000 meters.
3. Apparatus for receiving time signals (in connection with the regulation of clocks).

The advantages of the loop antenna are in its considerable reduction of those atmospheric disturbances of reception which, with high antennas and ordinary receivers, frequently hold up all traffic during the warmer months of the year for hours at a time. Furthermore, increased selectivity is obtained in that the same receiver discriminates between damped and continuous wave stations and, by utilizing the directional characteristics of the loop, enables picking one station signal to the more or less complete exclusion of a number of interfering stations.

In those cases where the strength of the incoming signal is ample for effective amplification, it is desirable to use an external heterodyne oscillator for beat reception.

The general arrangement of such an external oscillator used in conjunction with a loop receiving set of the former J. Berliner Company of Vienna is shown in Figure 8. Here *a* is the suspended rotatable loop, the received energy from which is connected by *b* to the receiver *c*. The telephone receiver is plugged into jacks in *c*. The external oscillator *f* is loosely coupled to the receiver *c*, for example, by placing *f* and *c* close to each other on the table. The intensity of the signals can be brought to the best value within limits by moving *f* on the table.

The external appearance of such an oscillator with its cover removed is shown in Figure 9. At the top are seen two ordinary amplifier tubes which are inserted into their sockets in the usual way. Besides these are the iron ballast resistances in hydrogen which tend to maintain constant filament currents. Below the tubes, and to the right is a rotary switch handle which permits choosing any one of three ranges of wave length extending in all from about 2,500 meters to 22,000 meters. The fine tuning to the desired wave length is done with the variable condenser placed at the left of the last-named switch. The handle of the variable condenser has two attached window indicators, one of which reads wave lengths on calibrated scales, and the other of which reads from 0° to 180°.

A switch for turning the filament current of the tubes on and off is placed below the condenser, and to the right of this switch are jacks for the plate and filament current batteries.

The loop-receiving set previously described enables covering the wave length range from 2,200 to 34,000 meters. Inasmuch as all tuning circuits, radio and audio frequency amplification circuits, detector, and regeneration control are included in the same apparatus, an unusually favorable combination is obtained both as regards portability and ease of operation.

It is not always necessary to cover so long a wave length range, and sometimes the separate parts of the set are desired. Thus, in Figure 10 is shown the exterior of a four-step radio frequency amplifier which is one of the component portions of the loop receiver. The whole receiving set can, then, be built up out of the following parts: loop, tuning means (generally merely a variable rotary plate condenser), four-step radio frequency amplifier, audio frequency amplifier, and such additional parts as storage batteries, high voltage battery, telephones, and so on.

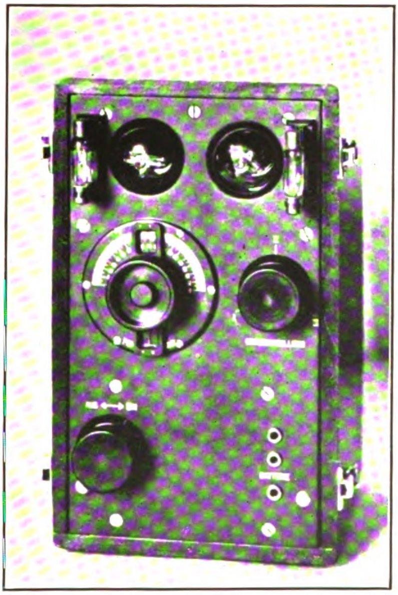

FIGURE 9

In the four-step amplifier of Figure 10, the first three tubes act as radio frequency amplifiers, and the fourth as a rectifying detector. The circuit is so arranged that no external oscillator is required for beat reception of continuous wave stations. This amplifier can be used with ordinary tuned-secondary receivers working with elevated antennas. In the amplifier shown in Figure 10, the windows in front of the four tubes are seen at the top, these tubes being inserted by lifting the top of the case. To the right, directly under the fourth tube, is a switch which not only turns the filament current on and off but regulates its value. The voltage across the tubes is indicated on the voltmeter to the left. Depressing the button under the voltmeter connects that instrument across the plate battery and permits measuring the plate voltage. To the right on the panel is the handle controlling the resistance for beat reception or plain detection, which handle also permits adjusting the local oscillations till optimum signal is obtained. The telephones are connected into the double jack at the right of the panel, the filament and plate batteries into the triple jack, and the connections to the tuning circuit are made from the double jack at the left of the panel.

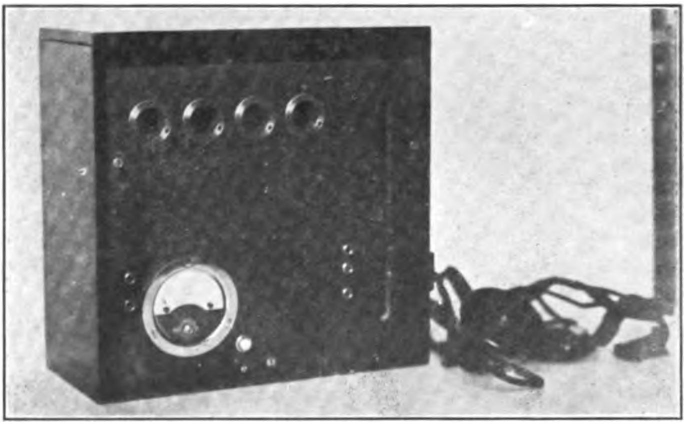

FIGURE 10

Directional receivers or radio goniometers were used in the World War on airplanes and otherwise. But their commercial applications are sure to increase in the future. For example, with the increasing use of aircraft, reception on the plane should also serve to guide the flight and permit safe descents to the landing field. Optical and accoustic means of positively locating the landing field have not proven adequate for the purpose.

The solution of the problem of finding the direction of the incoming waves at a receiving station is most easily and reliably attained by using two directional antennas in conjunction with a receiving goniometer. The type of goniometer built by the former Lorenz Company of Vienna is intended for use with two closed triangular antennas (loops) which can be very readily erected by the simplest means, and which gives greater accuracy in direction and freedom from locally produced errors than other methods.

The general arrangement is shown schematically in Figure 11. In this Figure, a_1, b_1 and a_2, b_2 are the pair of triangular antennas. The mast which supports them is only 9 meters (27.45 feet) high. The four small outer masts are 2 meters (6.1 feet) high and at a distance of 15 meters (45.75 feet) from the foot of the central mast. The planes of the two antennas must be perpendicular to each other, and it is convenient to arrange them in the East-West and North-South directions. The terminals a_1 are connected to the North-South binding posts of the goniometer and the terminals a_2 to the East-West posts of the goniometer. If the ends b_1 and b_2 are left open, a wave length range of from 150 to 760 meters can be covered in three steps. If the

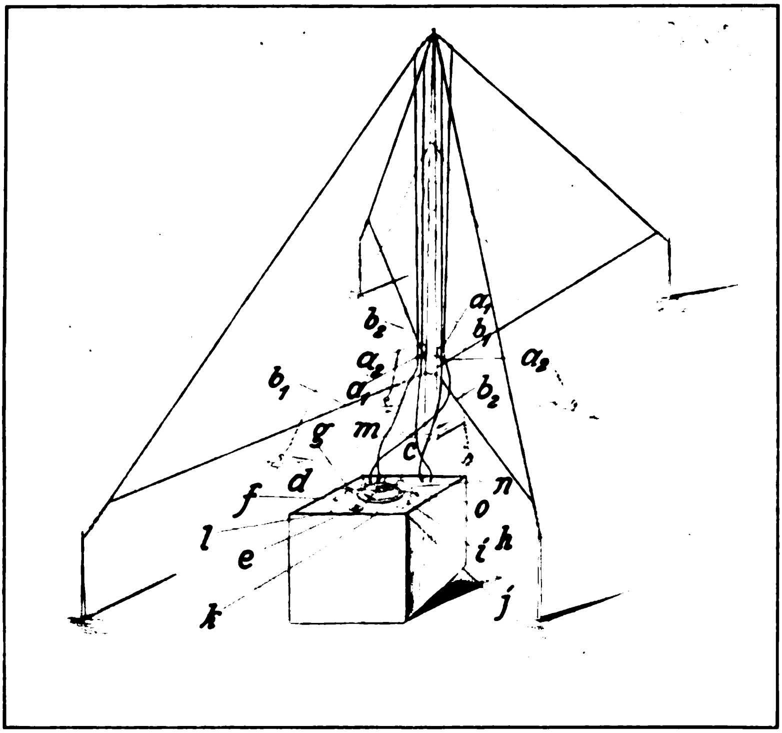

FIGURE 11

two ends b_1 are connected to each other, and the two ends b_2 similarly connected to each other, the wave length range is extended to 1,700 meters. If longer waves than 1,700 meters are to be received, there is connected between the terminals b_1 and b_2 a special piece of auxiliary apparatus, which has also been worked out by the former Lorenz Company, Limited, of Vienna.

The goniometer of the Lorenz Company of Vienna is worked out as a double receiver, with the necessary tuning elements permitting directional receptions of wave lengths between 150 and 750 meters embodied in the apparatus. Figure 12 shows the goniometer removed from its protecting case. It will be seen that there are two cylindrical coils, one mounted at right angles to the other and underneath it. The length, diameter, number of turns, and taps are so chosen that as uniform a field as possible is obtained, so that the cosine law of variation of induction with angular rotation is obtained for the short detector coil within each of the larger field coils. In order to secure the best value of coupling in each case, there is a detector circuit coil mounted within each cylindrical (field) coil. Both the detector coils are rigidly mounted on a common shaft which projects thru the top panel and carries the pointer *o* (Figure 11) which moves over a 0°-360° divided scale. It is, therefore, clear that when one of the detector coils is most closely coupled to its corresponding field coil, the other detector coil has practically zero coupling to its field coil. Inside the handle controlling the pointer *o* is a switch control enabling the choice between two detector couplings, and provided with a pointer designating "close" and "loose" coupling.

The ends of the detector coils are connected to the detectors *m* and *n*, either one of which can be selected for use by means of the switch *g*.

The telephone receivers or the input terminals of an amplifier can be plugged into the jacks *j*.

Any one of three wave length ranges can be chosen by means of the handle *c*. This handle controls a switch which connects all four antenna terminals to the correct conductors leading to the three windings on each of the cylindrical field coils. Dependent on the setting of switch *c*, the following wave length ranges are obtainable: 150 to 300 meters, 250 to 460 meters, and 410 to 760 meters.

Fine tuning is secured by the air condensers *e* which are mechanically coupled so that both antennas are simultaneously and correspondingly tuned. Small differences in their tuning may be compensated for by means of the condenser *f*. A switch *h* enables changing over the antennas from the upper to the lower cylindrical coils, according as the switch is set in positions I and III. In position II, the antennas are both grounded thru an earth connection to the binding post *i*, this being done when atmospheric disturbances threaten to injure the receiver or the detectors. If it is desired to extend the wave length range, ad-

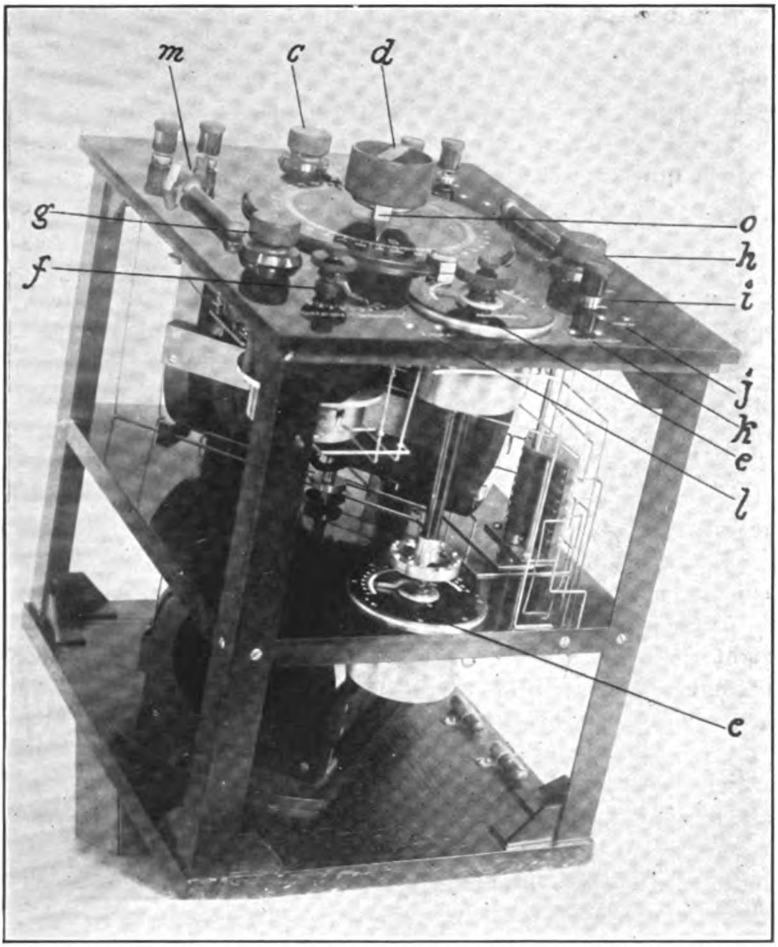

FIGURE 12

ditional condensers can be connected in parallel with the tuning condensers at the jacks *l* and *k*.

Radio measurements have recently assumed much increased importance. Thru the introduction of vacuum tube generators of radio frequency alternating currents and the use of beat reception, it has become possible to give to such measurements a very satisfactory precision.

The best way of meeting the various requirements for such measurements is to use high vacuum tubes (pliotrons) with appropriate circuits. It thus becomes possible to generate radio frequency currents which, being sustained, permit the obtaining of sharp resonance effects. These same currents remain quite constant over long periods of time. The use of expensive rotating machinery, with constant attendance, for the production of radio frequency energy is thus avoided.

The following assembly of apparatus for measuring purposes is built by the former Lorenz Company, Limited, from the designs of the author and Paul Floch. It is based on the possibility of combining all the necessary oscillating circuits and auxiliary apparatus required in conjunction with a tube for the important radio frequency measurements in one piece of apparatus of small dimensions. There is combined with this a calibrated secondary circuit which contains a calibrated inductance and capacity-free resistance.

Besides being used for measurement purposes, this apparatus can be employed as a continuous wave transmitter.

Both pieces of apparatus are shown in Figure 13. To the right is the tube generator or primary circuit, to the left the secondary or measuring circuit which can also be used in transmitting or receiving circuits when connected to the antenna.

The primary circuit consists of a three-electrode tube *a*, which receives its filament current from a battery connected to the binding posts *b*, and its plate circuit energy from a generator connected to the binding posts *c*. The variable air condenser *d* and the inductance *e*, the tapped sections of which can be inserted into the circuit thru a switch *g*, constitute the oscillating circuit. By varying *g* and the condenser *d*, the wave length of the oscillator for measurement, transmitting, or receiving purposes can be continuously varied from 150 meters to 1,200 meters.

A small secondary coil is mounted inside the cylindrical coil *e*. It can be rotated by means of the small handle *f*, which is provided with a graduated scale. The energy picked up by this small coil is used either to excite the secondary circuit or else the antenna. For this purpose the energy is transferred thru the conductors *h*. A small rotary switch *i* is provided with three settings, whereby the primary circuits is adapted to "Transmit," "Receive," or "Measure." The current thru the filament of the tube *a* is controlled by the handle *k* of a continuously variable resistance. A small hot wire ammeter *l* is provided, which measures the radio frequency current in the closed primary circuit. The filament current is measured by the moving coil ammeter *m*. At *n* are two jacks for plugging in a telephone receiver. A key *j* is provided which is used when the apparatus is employed as a continuous wave transmitter.

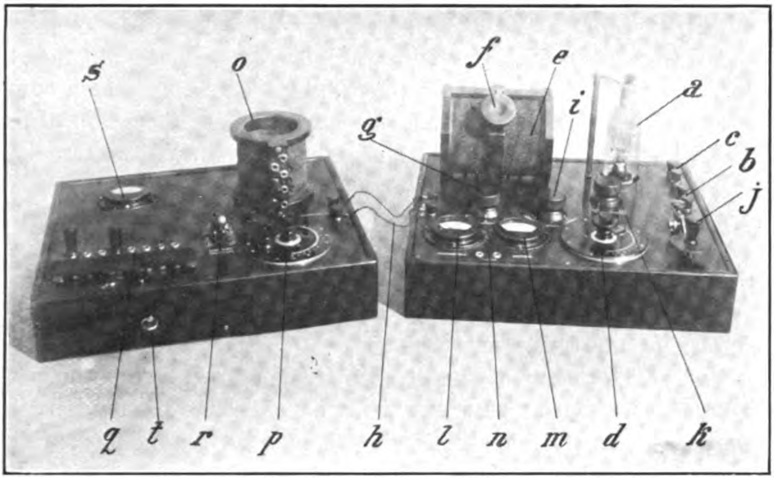

FIGURE 13

The secondary circuit is connected to the primary circuit by the previously mentioned conductor *h*. It consists of a tapped coil *o*. Two plug connections lead from this coil to the variable air condenser *p*, to a calibrated tapped resistance *q*, which may be plugged in as desired or short-circuited by means of the knife switch *r*, to a small hot wire meter *s*, and to a sensitive galvanometer, and three terminals behind the coil *o* which can be either partly short-circuited or connected to the oscillatory circuit under investigation, for example, the antenna system. The galvanometer and three terminals last mentioned are not shown in Figure 13. A small aperiodic circuit, not shown in the Figure, and containing an adjustable thermo-detector, is also provided to permit exact decrement measurements of relatively slightly damped systems (resonance circuits, antennas of low decrement, and so on). This circuit and detector can be connected by flexible conductors to the sensitive galvanometer. The aperiodic circuit itself is placed either on the resistance *q*, or, when very close coupling is desired, on the coil *o*. The energy transferred to the detector, and consequently the galvanometer deflection, may therefore be controlled between wide limits.

This assembly of apparatus consequently carrying out many of the measurements of radio telegraphy, can be used as a continuous wave transmitter, or for detector or beat reception, thus amplifying the effect of incoming continuous waves. Finally, the apparatus can be used for radio telephony, tho naturally only for short distances since the available energy is limited. Among the measurements which can be carried out are: measurement of the wave length and decrement of closed and open circuits, measurements of the constants of coils, condensers, insulating materials.

The development of small radio stations for use in trenches, airplanes, and so on gave rise to a considerable demand for a small, light, easily portable, and yet physically exact measuring apparatus. In view also of the long range of wave lengths now used in radio transmission, a continuous variation over this entire range is required.

These requirements have been met by the "pocket wave meter" shown ready for use in Figure 14. This was built by the former Lorenz Company, Limited, of Vienna, from the designs of the author. The outside dimensions of each of the small cases is 20 by 7 by 10 cm. (7.85 by 2.75 by 3.93 inches). They are therefore, about the same size as a cigar box. Nevertheless, the circuit elements are constructed in a physically satisfactory way inasmuch as the condenser has rotary plates in air, and the coils have been chosen as to their dimensions and number of turns to give a minimum decrement. Furthermore, the continuous wave length range of this meter, either for reception (measurement of wave length) or for sending with small energy (buzzer circuit of Eichhorn) extends from 50 to 6,000 meters. In addition, each wave meter is provided with a small aperiodic detector circuit, shown in the Figure, consisting of a coil, adjustable detector, and telephone which is plugged into place. This fits into the wave meter case, and is particularly useful when the wave meter is used for decrement measurements. This circuit may be coupled as loosely or closely as desired to the wave meter inductance, It is also possible to plug the antenna and ground into jacks on the wave meter and receive signals with primary circuit alone. In general, the resonance indicator used in this apparatus consists of a small hot wire "watt meter," which is provided with a special fuse to protect it against being burned out. If the energy available lies below certain limits, the aperiodic detector circuit and telephone receiver is used for locating the resonance setting. The wave meter is coupled to the system under investigation thru any one of the five available inductances.

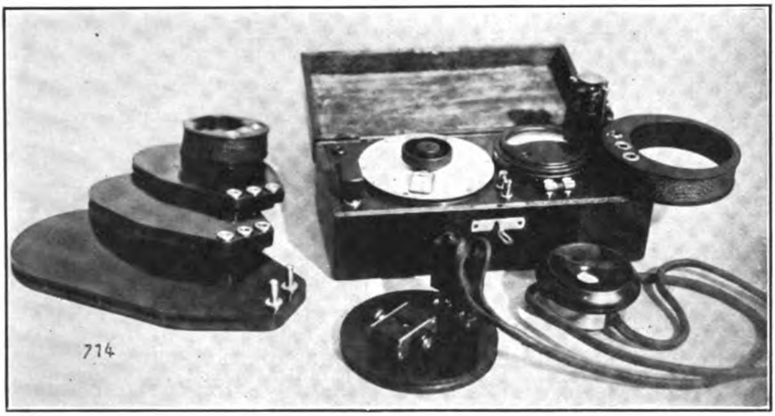

FIGURE 14

Vienna, June 2, 1920.

SUMMARY: After describing the general trend of radio development in Central Europe during and immediately after the war, there are described in detail a low power tube radiophone transmitter and receiver; a very short wave tube telegraph transmitting and receiving set; an audio frequency three-step amplifier; a complete loop antenna and receiving set having a four-step radio frequency amplifier, detector, and two-step audio frequency amplifier; an external heterodyne oscillator; a four-step radio frequency amplifier; a complete radio goniometer receiver; an assembly of apparatus for radio frequency measurements; and a portable wave meter.

RADIO TASTE RECEPTION*

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I. INTRODUCTION

Practically all reception of radio telegraphic signals of a practical nature which has been done up to the present time has been accomplished thru the sense of hearing of the operator. Some slight amount may have been done by using the operator's sense of sight, but this has never been found sufficiently satisfactory to warrant its use in practice. It was suggested by Mr. Arthur A. Isbell, that under certain operating conditions, for example, in places where there is great interference due to exterior noises, as in the case of the operator on an airplane, there might be a certain advantage in employing the operator's sense of taste rather than his sense of hearing in receiving signals. The object of this paper is to describe some tests made to determine the feasibility of reception of radio telegraphic signals by the sense of taste.

II. PRELIMINARY TESTS USING DIRECT CURRENT AND 60-CYCLE ALTERNATING CURRENT

1. TESTS USING DIRECT CURRENT

(*A*) APPARATUS

(*a*) ELECTRODES

The fact that a stinging taste sensation may be produced by placing the two wires of a low potential electric circuit on the tongue is well known. The first problem met with in investigating taste reception was to design a pair of electrodes which could be kept in the operator's mouth for a considerable length of time. It was, of course, necessary to choose for the metal of these electrodes some material which would not form injurious salts of the metal in the mouth of the operator. This limited the available metals to gold, platinum, or silver. Because of the prohibitive cost of the first two, silver was selected for use in these tests.

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Two electrodes were made of sheet silver about 0.016 inch (0.04 cm.) thick, 0.5 inch (1.27 cm.) wide, and 2 inches (5.08 cm.) long. They were separated by a piece of insulating material about 0.25 inch (0.63 cm.) thick. The construction is shown in Figure 1. It was intended that the tongue should be placed between the electrodes. Wires were brought from each electrode so that they might be connected to a source of potential.

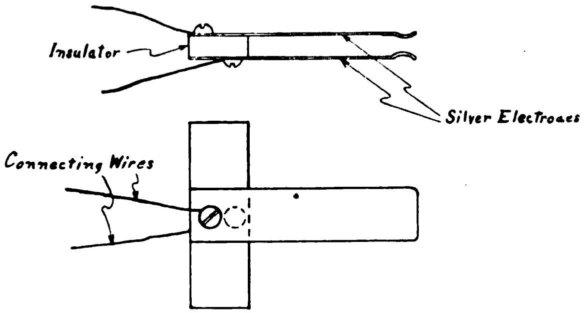

FIGURE 1

A few tests were made to determine the best position, pressure, and size of contact for the electrodes. It was found that placing the tongue between the electrodes as originally intended did not give the most satisfactory results. For the tests using direct current and 60-cycle alternating current, it was found better to have the electrodes slipped over the upper front teeth rather than the tongue. In this way one contact touched the inner part of the upper lip, while the other could be conveniently touched by the tip of the tongue. All the taste sensation was then confined to the tip of the tongue, which was found to be by far the most sensitive region in the mouth. The electrode touching the upper lip acted merely as a means for connecting that side of the circuit to the mouth.

In later tests made when using signals from a buzzer source, and signals from an antenna, it was found that the arrangement of electrodes just described was apt to cause painful sensations in the operator's front teeth. In an effort to prevent this, another disposition of the electrodes was tried. This was to have the ends of both contacts touch the tip of the tongue. This arrangement was found to give very good results. It had been tried previously when using the direct current and 60-cycle alternating current sources of potential, but had been found unsatisfactory, probably because of the relatively higher current and lower potential values common to such sources.

In all cases the best pressure between tongue and electrodes was found to be a firm, but by no means heavy pressure.

The electrodes should be small and should be close together so as to confine the taste sensation to a small area of the tongue and thus concentrate it. Two pieces of number 16 silver wire[1] 0.5 inch (1.27 cm.) long, separated about 0.125 inch (0.31 cm.) and partially imbedded in some insulating material would make very satisfactory electrodes for actual signal reception. The taste sensation should be obtained with the tip of the tongue, for this organ becomes increasingly insensitive toward its posterior portion.

(*b*) DIRECT CURRENT CIRCUIT

The circuit and instruments used in the d. c. tests are shown in Figure 2. Storage cells were used as the source of potential. The potentiometer was a 160-ohm sliding contact resistance connected as a potentiometer. The voltmeter had a range of 0-2 volt, and the milliammeter had a range of 0-1 milliampere. The contacts of an omnigraph could be substituted for the key shown in the figure.

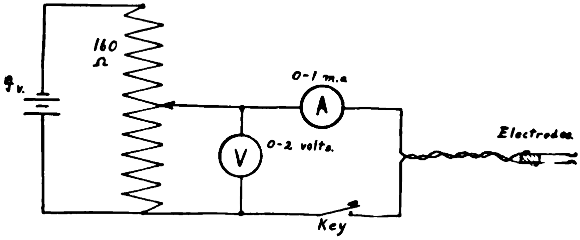

FIGURE 2

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[1] Diameter of number 16 wire = 0.05 inch = 0.013 cm.

(*B*) OBSERVATIONS

The first test that was made was to determine the constant potential necessary to produce the least noticeable taste sensation. It is quite probable that this potential would vary with different individuals, and possibly with the same individual at different times. The value necessary for the observer was $V = 0.4$ volt. For this potential, the current thru the tongue, as indicated by the milliammeter, was 0.01 milliampere. Tests were then made at higher potentials, the results obtained being as follows:

$V = 0.75$ volt. The tests made indicated that signaling would be impossible at this potential. The element of fatigue was strongly noticeable at this voltage. It was found that if the key were kept depressed for 5 seconds, it was impossible to detect the opening and closing of the key immediately after the continuous current period. In fact, it was generally necessary to rest for about 10 seconds before the opening and closing of the key could be again clearly noted. The current at this potential was about 0.02 milliampere. On first closing the key it is probable that the current was of the order of 0.1 milliampere for a short time. It fell quickly, however, to the lower value. This effect was probably due to the polarization phenomena which will be described later.

$V = 1.0$ volt. Using this potential it was found that the opening and closing of the key could be detected after an almost indefinite period of continuous current. It should be noted here that while it is stated that the opening and closing of the key could be noted, it was really only the closing that produced a noticeable sensation. With the potentials used up to this point, it was not possible to note the actual opening of the key by noticing the cessation of the taste sensation. The current at this potential was approximately 0.05 milliampere. On first closing the key it was probably about 0.2 milliampere.

$V = 1.5$ volts. Using this potential it was just possible to note the time of opening the key after a period of continuous current due to the cessation of the taste sensation. The current at this potential was approximately 0.1 milliampere. On first closing the key it was probably 0.2 milliampere. It would be possible to transmit signals very slowly (about 2 words per minute) at this potential.

$V = 2.0$ volts. The taste sensation obtained with this potential was considered sufficient for the practical transmission of signals. The probable speed of transmission would not be over

10 words per minute, and possibly no higher than 5 words per minute. The current at this potential was approximately 0.25 milliampere, and slightly higher than this on first closing the key.

(*C*) NOTES ON TASTE SENSATIONS

It is proposed to give herein the physiological effect of this method of reception on the operator, and to discuss certain electro-chemical phenomena in connection with the mouth electrodes.

It was noted that the taste sensation was more pronounced on first closing the key than after the key had been held down for some length of time. This was probably due to fatigue of the taste nerves on continuous excitation, and also to a partial polarization of the cell formed in the mouth. This latter effect would cause a decrease in the current, and thus a weaker sensation of taste. The fact, noted before, that the current was apparently higher on first closing the key seems to indicate that polarization was the deciding factor in this phenomena. This leads to the suggestion that alternating current might give better results than direct current as the source of potential, as the former would be free from polarization effects. It was found that the positive mouth electrode became blackened by a coating of oxide where the tongue made contact with it. As the other electrode did not become blackened at all, the nature of the polarization is clearly shown.

It will be remembered that in these preliminary tests one electrode made contact with the upper lip and the other was touched with the tongue. In the tests made so far, the latter had been connected to the positive pole of the battery. To determine whether the polarity of the tongue electrode would make any difference in the characteristics of the taste sensation, the polarity of the source of potential was reversed. It was found that the sensations were slightly less distinct when the negative pole was connected to the tongue electrode.

After this test the polarity of the electrodes was changed back to the original arrangement, and it was found that a much larger current now flowed in the mouth electrode circuit than had been obtained previously, using 2.0 volts potential. The current now obtained was 0.4 milliampere instead of the 0.25 milliampere previously recorded. On keeping the current on continuously it was found that the meter indicated a slow fall in the value of the current until the former value was approached. From this we conclude that the polarity of the electrodes had been reversed until the polarization of the cell in the mouth was such that it assisted the flow of current. After the current had flowed for a time, however, the polarity of the mouth cell became again reversed, and by opposing the battery potential, caused the value of the current to fall.

In connection with the increase in current just described, a peculiar effect on the sight of the operator was observed. On closing the key the operator noticed an effect which, at first, made him think that the lights in the room were flickering. On further investigation, however, it was noted that the apparent flicker of the lights occurred only when the key was closed. As nearly as could be determined, the effect of this relatively large current passing thru the mouth was to cause the iris of the operator's eyes to contract momentarily, thus giving the effect of a flickering of the lights in the room. A slight effect of a similar nature was noted on opening the key.

In connection with the reading of signals by taste, it was noted that the greatest difficulty was experienced in reading dots which were immediately preceded by dashes. The letter "c" (—.—.) was especially difficult to receive for this reason.

2. TESTS USING 60-CYCLE ALTERNATING CURRENT

(*A*) APPARATUS

The source of potential used was a 110-volt, 60-cycle generator. The circuit used is shown in Figure 3. The potential was impressed across the 160-ohm non-inductive resistance shown as *R′* in the figure. As the potentials needed in these tests were of the order of 1 or 2 volts, a second resistance, *R″*, was shunted around a portion of *R′*. As there was no a. c. voltmeter available for this work, which could be used to measure 1 or 2 volts, the potential impressed across *R″* was measured

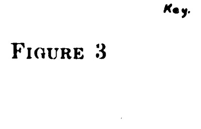

FIGURE 3

by an a. c. voltmeter having a range of 0-50 volts, and the potential impressed on the mouth electrodes was calculated. As R'' was just 15 inches (38 cm.) long (actual resistance wire winding), a potential of 15 volts was impressed across it. Thus there was a potential drop of one volt per inch of length along the winding. R'' was wound non-inductively like R'. As the amount of current taken by the mouth electrode circuit was small (not more than 0.5 milliampere) and as great accuracy as to the value of the potential was not essential, this method gave a value which was sufficiently exact for our purpose. No attempt was made to measure the current in the mouth electrode circuit.

(*B*) OBSERVATIONS

Tests were first made to determine the lowest alternating potential with which it was possible to obtain a taste sensation. This was found to be with approximately $V=0.5$ volt.

$V=1.0$ volt. Using this potential it was found possible to note the time of opening the key after a period of continuous current, by the cessation of the taste sensation. It would be possible to transmit signals very slowly at this potential. The definiteness of the signal in this case was about the same as that obtained using 1.5 volts d. c. It is hard to compare the two directly, for as will be described later, the nature of the taste is rather dissimilar for the two types of current.

$V=1.5$ volts. The taste sensation obtained using this potential was considered sufficient for practical transmission at a rate of 5 words per minute.

Higher speeds than this (10 words per minute) might possibly be obtained by using higher potentials. It is probable, however, that this increase in speed would be due to the operator's ability to read by muscular reaction instead of the sense of taste. As will be described later, this phenomenon of muscular reaction was quite noticeable at the higher potentials.

(*C*) NOTES ON TASTE SENSATIONS

The taste sensation accompanying the use of an alternating current source of potential differed from that obtained using direct current in the following ways:

1.—The element of fatigue did not seem to be so noticeable when using a. c. This may have been due to a slight variation of the taste with the alternations.

2.—The taste sensations did not appear to be any stronger than those obtained using the same potential d. c. However, it is probable that at the peak of each wave a larger current flowed than was the case with the d. c. The lack of any polarization phenomena with a. c. would lead to the belief that a somewhat larger current would be passed. The taste sensation was more continuous in its intensity when using a. c. than when using d. c.

3.—Combined with the taste sensation was the natural muscular reflex common to a. c., which was felt as a trembling in the tongue. At the higher voltages this was more noticeable than at the lower voltages. At 0.5 volt it was almost unnoticeable. It is probable that this muscular reaction was the principal reason for the taste sensations seeming to be more constant in intensity with a. c. than with d. c.

The more constant character of the taste sensation, combined with the slight muscular reaction obtained with a. c., made it possible to read signals, using a lower potential than was required with the d. c.

At higher potentials (2.0 to 3.0 volts) the same effect on the operator's eyes was noted that has been mentioned under the section on d.c. tests. As in the former case, the phenomenon was due to large values of current thru the mouth electrode circuit. In the a. c. tests a slight difference in the effect was noted. The operator not only noted a quivering of the eyes on first closing the key, but also a constant quivering as long as the key was held down. It was also noted that, for the same potential, the effect on first closing the key was not so marked as with d. c.

(*D*) REMARKS ON SIGNALS RECEIVED USING 60-CYCLE ALTERNATING CURRENT

The highest speed which the operator found it possible to receive by taste reception was 5 words per minute, and in order to do this it was necessary to become accustomed to this method of receiving, for it is quite dissimilar to audio-reception. It is possible that with sufficient practice an operator might be able to receive at a rate of 10 words per minute by taste reception. It is doubtful, however, if the speed could be increased much above that. The reason for this is what might be called the "lag" of the taste nerves. It has not been possible to determine whether this is due to an actual sluggishness in the nerves, or a mechanical inertia of the liquids in the mouth. It should be noted that a certain time is required for the chemicals which cause the taste sensation to form between the electrode and the tongue, and then that a further small period of time is necessary for them to be dissipated after the forming current has ceased. Regardless of the exact nature of the phenomenon, however, the fact is easily demonstrable that a fraction of a second elapses between the time the circuit is closed and the moment when the sensation of taste is first noted. Furthermore, a similar period may be noted after the current has ceased, when the taste sensation still persists. As nearly as could be ascertained, this time lag is from 0.25 to 0.5 a second. The effect of this is to slow down the permissible speed of signal transmission. It also necessitates a special type of sending. The dots and dashes must be of greater length than in ordinary transmission, and the spaces between the dots and dashes of a single letter must be longer than usual. As a consequence, of course, the spaces between letters and words must be correspondingly increased. All of these requirements limit the possible speed of reception.

3. CALCULATIONS TO DETERMINE THE PRACTICABILITY OF TASTE RECEPTION FROM AN ENERGY STANDPOINT

To determine whether it would be possible to use the taste receiver for the reception of actual radio signals, calculations were made on the basis of the data obtained in the d. c. and a.c. tests, to ascertain if the amount of energy ordinarily available in a small receiving antenna could be sufficiently amplified to be used for taste reception.

It has been found that the current in a 25-ohm antenna, necessary to produce unit audibility in the telephones, using a crystal detector, is 5 microamperes. As a basis for calculation, a signal giving an audibility of 1,000 was selected. The current in the antenna system for such a signal would be approximately 30 times that necessary for unit audibility, or 150×10^{-6}amperes.

In order to determine the voltage and energy amplification required to permit such a signal to be tasted, it was now necessary to ascertain the potential and energy available in the secondary or detector circuit.

Calculation showed that such a signal corresponded to an energy in the secondary circuit of approximately two-tenths of a micro-watt.

In the tests using direct current and 60-cycle alternating current it was found that about 2.0 volts potential was necessary for workable taste signals. The measurements made with d. c. indicated that this potential produced a current of about 0.25 milliampere in the mouth electrode circuit. In other words, the energy necessary for readable taste signals was about 500 micro-watts.

Comparing these values with those of the actual signal as found above, it is seen that the necessary voltage amplification is 50 times, and that the energy amplification is 2,500 times. As it is possible in practice to obtain voltage and energy amplifications of this order, there was justification for further investigation of the taste receiver, using actual signals as the source.

III. Tests Made with Radio Frequency Signals

1. Using Signals from a Buzzer Source

(*A*) Apparatus

(*a*) Circuits

It was decided to try signals from a buzzer source first, as these could be easily obtained and controlled. Accordingly, the circuit shown in Figure 4 was set up.

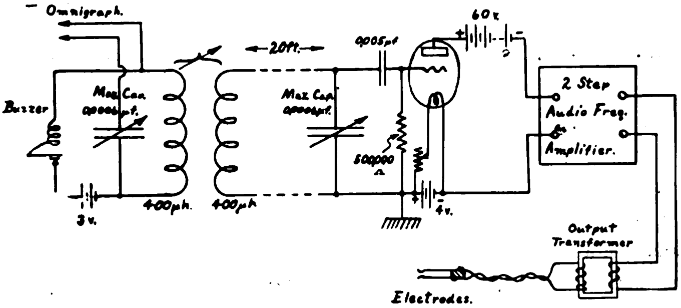

FIGURE 4

The circuits were tuned to a wave length of approximately 600 meters. The detector used was a vacuum tube. The plate potential employed was 60 volts. The capacity of the grid condenser was 0.005 μf., and the leak resistance between the grid and the plus side of the filament battery was 500,000 ohms. The amplifier used was a two-stage transformer-coupled amplifier giving a total voltage amplification of 150 times. The transformer between the amplifier and the mouth electrodes will be described later. An omnigraph was used in the usual way in the buzzer circuit to produce signals.

It was found necessary to ground the plus terminal of the filament battery to prevent the amplifier from howling. The amplifier bulbs were lit from the same battery as the detector bulbs. Separate plate batteries were used, however.

It was necessary to place the buzzer circuit across the room from the detector and amplifier circuits, because when placed nearby, the buzzer induced strong audio frequency currents in the amplifier circuits. The inductance coil of the receiving circuit was coupled to the buzzer inductance, and twisted leads were run across to the receiver circuit.

In these tests, the electrodes were placed about 0.125 inch (0.3 cm.) apart and touched to the operator's tongue. This was found to give better results for the reception of radio frequency signals than the method employed in connection with the d. c. and a. c. tests.

(*b*) OUTPUT TRANSFORMER

It was of course, impossible to connect the taste electrodes across the output terminals of the amplifier as the d. c. plate current of the last amplifier bulb would then pass thru the operator's tongue. It was, therefore, necessary to find a suitable transformer so that only the audio frequency a. c. would be obtained in the taste electrode circuit.

The following transformers were tried after consideration of the requirements:

Century Telephone Company, Air Core Transformer, number CAC 1013A.

Federal Telegraph and Telephone Company, Type 226W Transformer.

Western Electric Company, number 5 Induction Coil.

Western Electric Company, number 26A Repeating Coil.

In testing these transformers the following facts were noted:

A step-down ratio of transformation was necessary from the last step of the amplifier to the taste electrodes.

In the detector circuit, or with only one stage of amplification, a 1-to-1 ratio was best. As would be expected, the higher the amplification, the greater the necessary lowering of the voltage for proper reception.

The requirements of the taste receiver seemed to necessitate the use of a power transformer, that is, one capable of handling considerable energy while acting as a potential transformer.

The following figures give the relative strength of the taste sensation obtained, using the four transformers mentioned above, taking the intensity given by the Federal Company's transformer as 5:

Western Electric Company, number 5 Induction Coil (reversed)	0
Century Telephone Company, number CAC 1013A (step-down)	1
Western Electric Company, number 26A Repeating Coil (step-down 3-to-1)	4
Federal Telegraph and Telephone Company, Type 226W (step-down)	5

As the Type 226 W Transformer of the Federal Company gave the most satisfactory results, it was used in the tests which are described below.

(*B*) OBSERVATIONS

The coupling between the buzzer circuit and receiving circuit inductances was increased until a taste sensation was obtained which was of the proper strength for signaling. Measurements were then made of the audibility of the signal in the detector circuit by the usual shunted telephone method. In making the measurements a pair of Western Electric Company Type P-11 telephone receivers were used. These telephones have an impedance of 22,000 ohms at 500 cycles. A decade resistance box was used to shunt the telephones. It was found that the signal of the proper intensity after two stages of amplification to permit of reception by taste, had an audibility of 500 in the detector circuit.

It was thought that a possible increase in the intensity of the taste sensation might be brought about by tuning the mouth electrode circuit to the audio-frequency tone of the buzzer. Values of capacity from 0.05 μf. to 4.0 μf., were tried in series with the transformer winding and mouth electrodes. With a condenser of 1.0 μf. capacity in series, the taste sensation was of the same intensity as when no capacity was in the circuit. With all other values, however, the insertion of the condenser decreased the intensity.

2. USING SIGNALS FROM AN ANTENNA

(*A*) APPARATUS

For the purpose of receiving outside signals, an ordinary inductively coupled vacuum tube receiver was employed. The antenna used was a single wire, 150 feet (45.8 m.) high and 180 feet (54.9 m.) long. It was found necessary to use four stages of audio-frequency amplification in order to get taste sensations of the proper intensity. Two sets of two-stage transformer-coupled amplifiers were connected in cascade. By separating them about ten feet (3 m.), it was possible to get rid of the howling tendency sufficiently for the purpose of taste reception, provided the operator, who was connected to one amplifier, did not go too near the other. The reason for needing a greater amplification in this test than in the tests using buzzer signals was probably that the antenna used had a very high resistance, and thus altho the voltage amplification obtained with a two-stage amplifier would have been sufficient, the actual energy available at the end of the second step was not sufficient for taste reception.

(*B*) OBSERVATIONS

With four stages of amplification it was possible to get taste sensations from all signals, the audibility of which in the detector circuit was 500 or more. The higher the audibility of the signal, the stronger was the taste sensation produced. The strongest signal received had an audibility of 5,000 in the detector circuit. The taste sensations resulting from this signal were not strong enough to cause discomfort for the operator. Whether or not a signal might be obtained of sufficient intensity to cause discomfort to the operator, would depend on the amount of energy which the last stage of the amplifier could handle.

As the signals received were commercial messages, their speed prevented them from being read by taste reception, but the intensity was sufficient to permit of their having been read had the sending been slower. It was found possible to tune in a station by noting when the intensity of the taste sensation was greatest. It was also noted that a slight difference existed between the taste sensation produced by a 240-cycle spark transmitter and a 500-cycle spark transmitter. The difference was not sufficient to permit of one being received thru the other, as could be done with audio-reception. It would be impossible to read thru interference with the taste receiver unless one signal was quite strong and the other almost unnoticeable. Strong strays would probably cause signals to become unreadable.

IV. CONCLUSIONS

1 ELECTRICAL ASPECTS

From the point of view of electrical operation, taste reception is possible. It is possible to amplify sufficiently a signal having an audibility of 500 in the detector circuit, to cause it to produce taste sensations. It is possible to read signals by the sense of taste if they are sent at a slow speed (about 5 to 10 words per minute).

2 MECHANICAL ASPECTS

At best, the mechanism of taste reception is unpleasant for the operator. A pair of head telephones which may be adjusted snugly to the ears are greatly superior in point of physical comfort to a pair of electrodes which must be held in the mouth, pressed against the tip of the tongue. There is also the disadvantage of the slow speed of transmission necessary for taste reception.

3 PHYSIOLOGICAL ASPECTS

The nerves of taste become fatigued by continued stimulations, and this will necessitate an increasingly higher amplification of energy if the operator is to be on duty for any considerable length of time. The effect on the operator's eyes of contracting the iris when very strong signals are received would be very disadvantageous, especially in airplanes. The taste sensation is a sour stinging taste which is far from pleasant. With high amplification and strong signals or strays, the taste sensations might be so strong as to be distinctly objectionable.

4 PSYCHOLOGICAL ASPECTS

Since the time when the progenitors of the human race began to communicate with each other by different sorts of sounds, the natural mode of communication between individuals has been by means of sounds. Thus the ear has become the organ which is developed from babyhood for the especial purpose of receiving intelligence. It is only natural, therefore, that this sense should be easily adaptable to the receiving of telegraphic signals. Its highly developed power of selectivity enables it to read only one of a number of signals or noises which may be heard at the same time.

The other sense by means of which intelligence is communicated, that is, sight, is valuable particularly because of its development in reading. In this way it often may be used to partially take the place of the sense of hearing, as in the case of lip reading employed by deaf persons. For the purpose of mechanical signaling it is useful in its ability to read from a tape record, and possibly also from the flashing of a light.

The sense of taste is naturally unfitted, because of lack of previous training along such lines, for the task of associating impulses sent to it with the necessary accurate motor responses required for the copying of transmitted intelligence. In making the tests which have been described, it was noted that great concentration of thought, upon the sense in question, was required in order that the nature of the received impulses might be noted. This indicates that the association is a difficult and unnatural one. Furthermore, it should be noted that if great concentration is necessary in order to receive by this method, it certainly would be impracticable in an airplane where the noise would effectively prevent concentration.

With the amplifications and signal intensities used in the tests on taste reception, it would be possible to read signals by audio-reception in spite of any strength of interfering noise which the ear of man could endure.

In conclusion we wish to thank Mr. Carl Dreher of this Laboratory for his assistance in making the signal speed tests.

Research Department,
Radio Corporation of America,
December 31, 1919.

SUMMARY: The purpose of this research was to determine the feasibility of reception of radio telegraphic signals by the sense of taste.

Electrodes were made which could be placed against the tongue in such a way as to cause a taste sensation when a source of potential was connected to them. Tests were made, using low potential direct current and 60-cycle alternating current to ascertain the amount of energy and potential necessary for taste reception.

Tests were then made, using signals from a buzzer source. By employing a two-stage transformer-coupled audio-frequency amplifier it was possible to obtain taste sensations from a signal having an audibility of 500 in the detector circuit. The possible speed of transmission appeared to be limited to a maximum of about 10 words per minute because of the characteristics of the taste organs.

Finally, the reception of actual signals from an antenna was tried. It was found possible by using four stages of amplification to obtain taste sensations from all signals the audibility of which was greater than 500 in the detector circuit.

The results obtained thus indicate that from an electrical standpoint it is possible to receive radio telegraphic signals by the sense of taste. When compared to the sense of hearing or even of sight, however, the sense of taste is much inferior as a means for receiving intelligence.

DISCUSSION

Greenleaf W. Pickard: Messrs. Goldsmith and Dickey have undoubtedly broken new ground in their work on physiological reception of radio signals, and altho the results thus far obtained do not indicate that their method will generally replace aural reception or the more recent Hoxie recorder, it is certainly within the bounds of possibility that some such form of reception may develop into a practical thing for special cases of reception. The suggestion of physiological reception is one of some antiquity. In 1894 Lodge said[1] "It is just conceivable that at some distant date, say by dint of inserting gold wires or powder in the retina, we may be enabled to see waves which at present we are blind to." Some eight years later, A. F. Collins stuck platinum needles into the brain of an etherized cat, which then twitched synchronously with the excitation of a near-by Hertzian oscillator.[2]

In discussing the pioneer work of this character, one is tempted to go beyond the confines of the paper itself, and to consider the possibilities of physiological signal reception by the various senses. At the outset, one is impressed by the fact that the peripheral sense organs of sight, hearing, taste, and smell are very similar in size and appearance.

In Figure 1, I have shown the peripheral sense organs of sight, hearing, taste and smell. In each case the sense organ consists of a cell-body *a*, with a nucleus *b*, a peripheral process *c*, which in the sense organs of hearing, taste and smell terminates in one or more hair-like filaments, and a central process *d* thru which the sense organ is connected to the nervous system. The stimulus is in each case received by the peripheral process *c*, and then, by some as yet unknown mechanism, it is transformed into an equally unknown pulse which travels rather leisurely—about 30 meters (100 ft.) per second—thru the nervous system. The transmission of a nervous impulse appears to be a chemical process; a sort of sudden evanescent increase in the normal metabolism of the nerve.

Whatever the mechanism of the action, the amount of energy required for a perceptible sensation is impressively small. In Figure 2, I have given a table for the four senses under consideration, and in the second column of this table is the "threshold" value of the stimulus energy required to excite the sense.

Sight appears to be our best sense, so far as energy relations go, and it is interesting to note that it is exactly on a par with the

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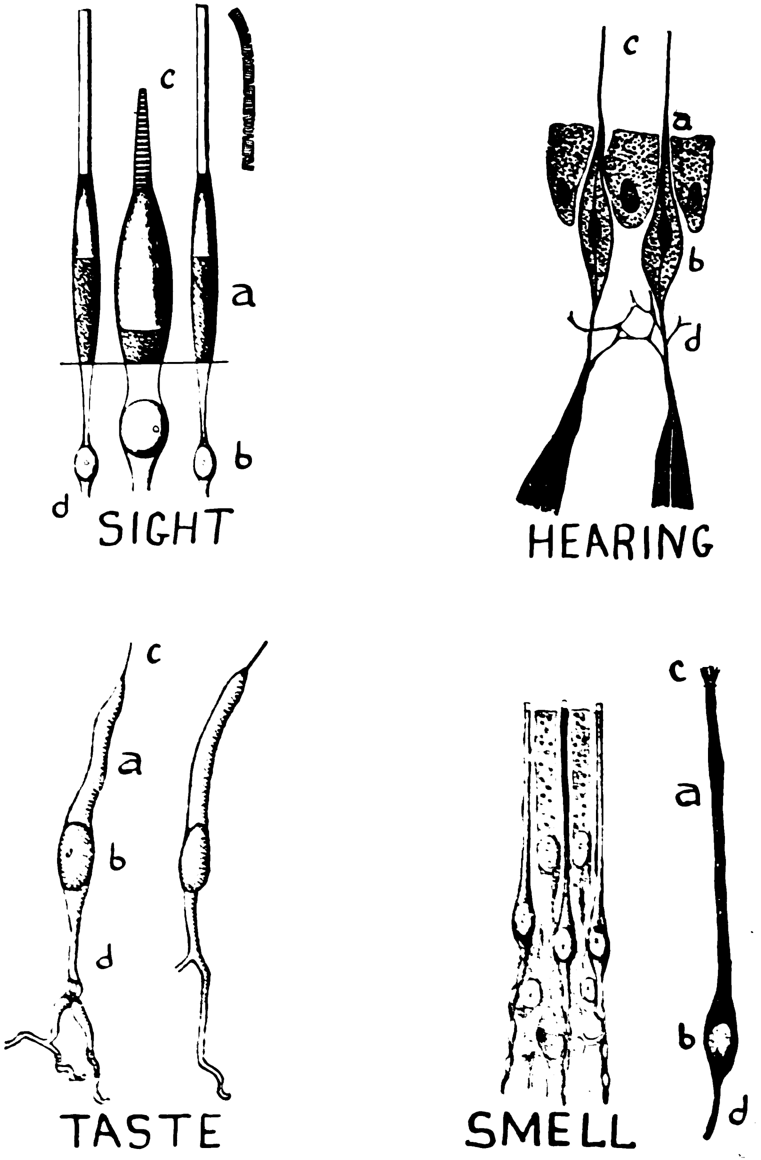
[1] "London Electrician," June 22, 1894, page 204.
[2] "Electrical World and Engineer," February 22, 1902, pages 335-338.



SIGHT

HEARING

TASTE

SMELL

FIGURE 1

Sense	Minimum to Excite Sense	Perception Interval	Words per Minute
Sight[3]	10^{-9} erg/sec.	0.1 sec.	9 to 13
Hearing	10^{-8} "	0.007 "	30 to 40
Taste	10^{-2} "	1?	2?
Smell	10^{-2} "	1?	1?

FIGURE 2

oscillating audion as a detector, which also requires 10^{-9} erg/sec. for unity audibility. Taste and smell, similarly, are of the same order of sensitiveness as the crystal detector, altho our measurements of their sensitiveness are far less accurate than with sight or hearing. If, therefore, we could effectively use our received signal energy to stimulate our senses, they would be surprisingly good detectors *per se*. It is within the bounds of imagination at least that investigation will solve the problem of effectively applying the energy, preferably without a major surgical operation, or even Lodge's suggested retinal stitching and powdering. The sense organ of the ear is unfortunately rather deeply buried, otherwise one might speculate on the possibility of direct physiological reception in radio-telephony.

During the discussion, Mr. George Clark has pointed out that the actual speed of reception by light signaling is often greater than that given in my table. But the higher speeds of visual reception are only obtained by moving the image point about on the retina, thus spreading out the dots and dashes into a string of after-images, which may be interpreted at leisure—the word "leisure" here being used in a strictly relative sense, meaning merely the few tenths of a second that the after images last. Where the image of the signal light falls steadily on one spot on the retina, I do not believe that a greater speed than about ten words per minute can be obtained. Similarly, my table gives the approximate speed in words per minute for pure taste reception, as determined on my tongue with alternating sweet and bitter tastes. In the work described in this paper, I believe that the sensation utilized must have been in reality a complex of taste and electrical shock. The few tests which I have so far made with signal reception by pure shock indicate that the speed is quite high, perhaps of the order of ten words per minute or more. It has been mentioned in the discussion of the paper that some form of physiological reception involving the tongue was used by telegraph operators during our Civil War, and at speeds approximating those of ordinary wire working. I have no doubt but that this was principally a matter of electrical shock, as the potentials involved were certainly high enough, when directly applied to wet and sensitive tissues.

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[3] "Speeds in Signaling by the Use of Light," W. E. Forsythe, "Physical Review," July, 1920, pages 62-64.

In conclusion, it occurs to me that a form of local energy (not the heterodyne) might be applied to physiological reception. Some years ago Professor Fessenden suggested the use of a Poulsen telegraphone as a detector, in which the steel wire carried a continuous audio-frequency record, which was obliterated by the received signals, so that by sending inverted morse, that is, the spaces instead of the characters, a reversed and readable record was obtained. It is possible that something of this sort might be applied here. It seems that high frequency currents act rather to dull and inhibit the action of nerve and muscle than to stimulate, so that by superposing the signal upon some form of continuous local stimulus (not necessarily electrical), it might be possible to increase the speed and sensitiveness of the method.

A SYSTEM FOR MEASURING THE AMOUNT OF STATIC*

By

Austen M. Curtis

(Western Electric Company, New York)

It is necessary in studying systems for the elimination of static to have some means for measuring the relation of static to signals. The method of estimating the efficiency of various receiving systems by the percentage of errors in reception caused by static is not particularly accurate, as different operators do not have the same ability to read thru static. Large momentary variations in the intensity of static make its measurement by the shunted telephone method of doubtful value. The following method of time integration was devised in an effort to measure the average amount of static.

The circuit used is shown in the accompanying sketch. An audiofrequency transformer is connected in series with or in place of the telephones of any type of receiving set. The static, which has been converted into audible frequency waves by the detector, is passed into a vacuum tube valve or combination of valves at an increased voltage, and completely rectified. The resultant direct current pulses are used to charge a very large condenser, which is discharged slowly thru a galvanometer in series with a high resistance. If the condenser and the resistance are large enough, the static will cause a reasonably steady deflection of the galvanometer. This deflection will depend on the average intensity and frequency of occurrence of the static during a time which is short compared to the time constant of the galvanometer circuit. For instance, if 100 microfarads and one megohm are used, the deflection produced by a single crash of static will drop to about one-third its initial value in one hundred seconds. Where the usual static, which occurs in crashes every few seconds, is concerned, smaller capacities and resistances will give satisfactory measurements.

With a pivot galvanometer giving one division for two micro-

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* Received by the Editor, May 19, 1920.

amperes, a capacity of 40 microfarads and 500,000 ohms resistance, it is possible to make satisfactory readings of the static on a receiving system with several stages of amplification. With a galvanometer of higher sensitivity, the time constant may be made larger and steadier readings obtained. A practical limit is put on the attainable time constant by the leakance of commercial paper condensers, which is of the order of 2,000 megohms per microfarad.

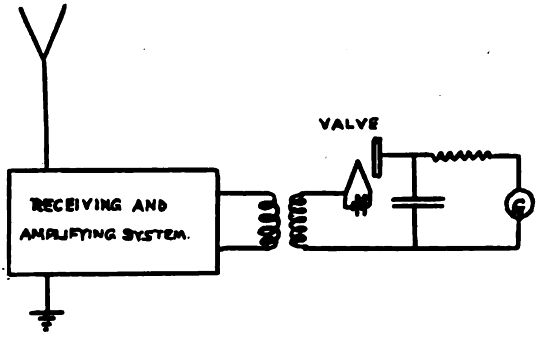

FIGURE 1—System for Measuring the Quantity of Static

It seems probable that the use of this system of static measurement would enable a reliable determination of the direction from which static comes to be made on a single loop receiving system. It would, of course, be necessary to listen in every minute or two, to see that the readings were not influenced by signals of an intensity comparable to the static.

It is also possible to standardize static measuring systems of this type and establish a basis for comparison of the amounts of static received at different stations at the same time. It would be necessary to apply to the detector of each station, at various frequencies, a wave modulated in a known amount at a known voltage. The amplification at each station might then be adjusted until the same deflection was produced in the static measuring system of each station by a given voltage applied to the detector, or the ratios of the detector voltages necessary to produce the same deflections at the same wave lengths in the various stations might be used to reduce the static readings to a common basis. The calibration might be made by an ordinary oscillating circuit excited by a carefully adjusted buzzer, preferably of a low vibration frequency.

SUMMARY: Amplified and rectified energy from static is stored in a large condenser in the output circuit of a vacuum tube. The condenser discharge current thru a high resistance and sensitive galvanometer will, under given conditions, be a measure of the average static. The experimental arrangements are described, as to calibration and actual use.

ON THE POULSEN ARC IN COUPLED CIRCUITS*

By

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1. INTRODUCTION

The Poulsen arc generator in connection with coupled circuits has been used by V. Poulsen[1] at a comparatively early date. Rather close coupling was often used by him in his radio telegraphic tests,[2] whereas he usually employed comparatively loose coupling in the series of tests by which long distance radio telephony[3] was, for the first time, shown to be feasible.

Arc oscillations in coupled circuits have been the subject of a number of laboratory investigations as well as of theoretical studies. In this connection may be mentioned the investigations on musical (audio frequency) arcs by E. Taylor Jones,[4] E. Taylor Jones and M. Owen,[5] E. Taylor Jones and D. E. Roberts,[6] and S. Subkis;[7] and on radio frequency arcs by P. O. Pedersen[8] and Hidetsugu Yagi.[9]

The author himself carried out a series of investigations on the Poulsen arc in coupled circuits in the autumn of 1918. He employed for these investigations, among other arrangements, the one shown in Figure 1 where L_1 is considerably larger than

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*Received by the Editor, April 10, 1920.

[1] See U. S. Patents, numbers 789, 449 and 793, 608; filed June, 1903.

[2] V. Poulsen: "Ein Verfahren zur Erzeugung ungedämpfter Schwingungen und seine Anwendung in der drahtlosen Telegraphie," "Elektrotech. Zeitschrift," pages 1040-1044, 1906 (Figure 8).

[3] V. Poulsen: "La téléphonie sans fil." "Rapport officiel au Congrès international des applications électriques," Turin, 1911.

[4] E. Taylor Jones: "Electrical Oscillations in Coupled Circuits," "Phil. Mag.," (6), volume 17, pages 28-43, 1909.

[5] E. Taylor Jones and M. Owen: "Musical Arc Oscillations in Coupled Circuits," "Phil. Mag.," (6), volume 18, pages 713-722, 1909.

[6] E. Taylor Jones and D. E. Roberts: "Phil. Mag.," (6), volume 20, pages 660-663, 1910.

[7] S. Subkis: "Der Einfluss der Koppelung bei langsamen ungedämpften Schwingungen," "Jahrbuch d. drahtlosen Telegraphie," volume 5, pages 507-513, 545-563, 1912.

[8] P. O. Pedersen: "Beiträge zur Theorie der drahtlosen Telephonie," "Jahrbuch d. Drahtlosen Telegraphie," volume 5, pages 449-498, 1912.

[9] Hidetsugu Yagi: "Arc Oscillations in Coupled Circuits," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 4, pages 371-388, 1916.

L_2', and he obtained a current I_2 in the secondary circuit 2 to 3 times larger than the current I_1 in the primary circuit (arc-circuit), whereas I_1 at the same time kept its normal value $\sqrt{\frac{1}{2}}\,I_o$, where I_o is the supply current.[10] (During these tests the wave-length was $\lambda = 7{,}700$ m., the resistance $R_2 = 3$ to 4 ohms, and the capacity $C_2 = 32{,}000$ cm. or 0.036 microfarad.) These tests were discontinued in order that some investigations on the arc generator proper might be carried out, and it is hoped to get the opportunity later on of publishing, in another paper, the results thereof. Before discontinuing the above-mentioned tests, there had, however, been carried out a series of investigations on a special arrangement of coupled circuits which is shown in Figure 2 and which, as far as I am aware, has been introduced by L. F. Fuller[11] and by Hartenstein[12] independently of each other.

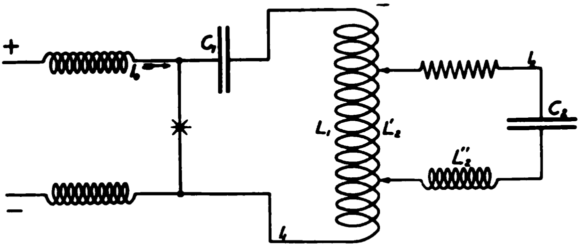

FIGURE 1

2. INVESTIGATION OF THE CIRCUIT SHOWN IN FIGURE 2

The distinctive feature of this diagram is that a condenser C_2 is inserted next to the arc, in series therewith and with the aerial, and further that the arc and C_2 are shunted by another condenser C_1. In the following treatment, C_1 is at times called the "shunt condenser" and C_2 "series condenser." If C_1 be disconnected, the diagram is reduced to the usual and simple one merely containing an extra condenser C_2 inserted into the antenna. The wave-length λ_o is, in this case (in meters):

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[10] P. O. Pedersen, (a) "On the Poulsen Arc and Its Theory," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, pages 255-316, 1917. (b) "Supplementary Note," volume 7, pages 293-297, 1919.

[11] L. F. Fuller, U. S. Patent, number 1,179,353, filed April, 1913.

[12] H. Rein, "Lehrbuch der drahtlosen Telegraphie," second edition, pages 182-183, 1917.

$$\lambda_o = 6\pi \cdot 10^8 \sqrt{L C} \cdot \sqrt{\frac{C_2}{C_1 + C_2}} \tag{1}$$

By connecting the shunt condenser to the circuit the wave-length will assume a new value λ being determined by the condition that the radio frequency circuit between A and B must be in resonance for that wave-length.

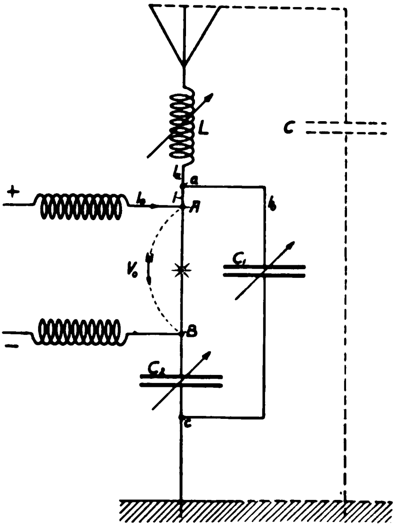

FIGURE 2

We will use the following symbols: $n \cdot \lambda = 3 \times 10^8$; $2\pi n = \omega$; $\sqrt{-1} = j$; the antenna capacity $= C$; the impedance of the radio frequency circuit between A and $B = Z$; the admittance of the circuit $a L C c = Y_a$; the admittance of the circuit $a C_1 c = Y_b$.

We have consequently

$$Z = j \frac{C + C_1 + C_2 - \omega^2 L \cdot C \cdot (C_1 + C_2)}{\omega C_2 \cdot (\omega^2 L C C_1 - C - C_1)} \tag{2}$$

The circuit is in resonance for $Z = 0$, from which it follows that

$$\omega = \sqrt{\frac{C + C_1 + C_2}{L C (C_1 + C_2)}} \tag{3}$$

The length of the radiated wave in meters is, therefore, determined by

$$\lambda = 6\pi \cdot 10^8 \cdot \sqrt{LC} \cdot \sqrt{\frac{C_1+C_2}{C+C_1+C_2}} \tag{4}$$

which, in combination with (1), gives

$$\frac{\lambda}{\lambda_o} = \sqrt{1 + \frac{C \cdot C_1}{C_2\,(C+C_1+C_2)}} \tag{5}$$

It is evident that λ is always larger than λ_o, which, it seems, has not always been taken fully into consideration.

In the above calculations no regard is paid to the resistances in the radio frequency circuits, because these resistances are of very small importance in the determination of the wave-length; furthermore, the calculations would be very much complicated if the resistances were taken into account.

We have carried out a series of measurements of sets of λ and λ_o in order to make sure that the above considerations hold good. The results of these measurements are shown in Table 1 below.

TABLE 1

				λ		$100\frac{\lambda-\lambda_o}{\lambda}$	
C cm.	C_1 cm.	C_2 cm.	λ_o m.	measured m.	calculated m.	measured	calculated
7,300	1,250	14,600	3,440	3,490	3,487	1.45	1.35
7,300	14,600	14,600	3,810	4,200	4,225	10.3	10.9
6,400	7,400	12,500	3,800	4,060	4,066	6.85	7.0
13,800	13,050	39,600	6,860	7,080	7,090	3.2	3.3
13,800	600	14,600	5,400	5,500	5,455	1.8	1.0
13,800	1.200	14,600	5,400	5,560	5,503	3.0	1.9
13,800	2,000	14,600	5,400	5,620	5,567	4.1	3.1
13,800	2,400	14,600	5,400	5,660	5,594	4.8	3.6
13,800	4,400	14,600	5,400	5,800	5,735	7.4	6.2
13,800	5,600	14,600	5,400	5,900	5,805	9.3	7.5
13,800	7,600	14,600	5,400	5,980	5,913	10.8	9.5
13,800	10,350	14,600	5,400	6,100	6,048	13.0	12.0
13,800	13,250	14,600	5,400	6,120	6,160	13.3	14.1

Taking into account that the values given above for the capacities of the condensers may be wrong by about 0.5 per cent., the measured values of λ may be considered to agree quite satisfactorily with the values as calculated from equation (5). There can, consequently, be no doubt that the above calculations are correct, and that it therefore is possible to calculate in the usual way how the radio frequency arc current (wave-length λ) divides itself between the two circuits (a) I_a in $aLCc$ and (b) I_b in aC_1c. If, as before, the resistances are not taken into account we obtain by means of (3)

$$Y_a = \frac{j\omega C}{1-\omega^2 LC} = -j\frac{1}{\omega L}\frac{C+C_1+C_2}{C} \tag{6}$$

and

$$Y_b = j\omega C_1 = j\frac{1}{\omega L}\frac{C+C_1+C_2}{C}\frac{C_1}{C_1+C_2} \tag{7}$$

Furthermore,

$$Y_a + Y_b = -j\cdot\frac{1}{\omega L}\frac{C+C_1+C_2}{C}\frac{C_2}{C_1+C_2} \tag{8}$$

From the above, we derive

$$\frac{I_a}{I} = \frac{Y_a}{Y_a+Y_b} = 1+\frac{C_1}{C_2} \tag{9}$$

$$\frac{I_b}{I} = -\frac{Y_b}{Y_a+Y_b} = \frac{C_1}{C_2} \tag{10}$$

and

$$\frac{I_b}{I_a} = -\frac{Y_b}{Y_a} = \frac{C_1}{C_1+C_2} \tag{11}$$

We note that I and I_a are in phase, whereas I_b is of opposite phase to I and I_a.

It may not appear to be correct to disregard the resistances when the calculation deals with the distribution of the currents between the two circuits. The resulting error is, however, small; which may be shown as follows:

In the above calculations the impedance Z_a of the circuit $aLCc$ has been taken as

$$Z_a = j\omega L\frac{C}{C+C_1+C_2}$$

whereas the real value is

$$Z_a' = R + j\omega L\frac{C}{C+C_1+C_2}$$

If, in these equations, we take $\omega = 400{,}000$, $L = 10^{-3}$ henry, and $\frac{C}{C+C_1+C_2} = \frac{1}{4}$, we have

$$Z_a = j\cdot 100 \quad\text{and}\quad Z_a' = R + j\cdot 100$$

Assuming $R = 5$ ohms (which is a comparatively high value) we obtain the ratio of the absolute values of the impedances

$$\frac{Z_a'}{Z_a} = \frac{100.1}{100} = 1.001$$

The difference between the true value of Z and the value used in the calculations is therefore only 0.1 per cent.

If, therefore, the total radio frequency current is of the wave-length λ, that is, if no harmonics or other oscillations of a wave-length differing from λ are present, it must be expected that the current will distribute itself according to equation (11).

In Figure 3 are plotted the results of a series of measurements of the simultaneous values of the currents. Curve A shows the ratio $\frac{I_a}{I}$ between the antenna current and the arc radio frequency current; curve B shows the ratio $\frac{I_b}{I_a}$ between the shunt current and the antenna current, and curve C shows the ratio $\frac{I}{I_0}$ between the arc radio frequency current and the arc direct current. The curves are plotted as functions of the capacity of the shunt condenser. (The other constants were: $\lambda_0 = 5{,}400$ m.; $C = 13{,}800$ cm.; $C_2 = 14{,}600$ cm.; and R = about 3 ohms.) The corresponding theoretical curves, as based upon the equations (9) to (11), are indicated by the curves A', B', and C'.

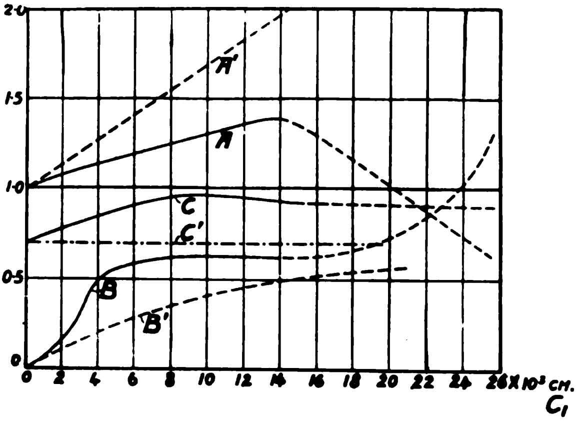

FIGURE 3

It will be seen that the measured curves differ to a considerable extent from the theoretical curves, the antenna currents being much less and the shunt currents comparatively much greater than what they should be. The reason for this is, that in addition to the fundamental oscillation of wave-length λ, a series of oscillations with shorter wave-lengths are created, these latter being partly the higher harmonics of the fundamental oscillation and partly the fundamental of the circuit arc—$A a C_1 c - C_2 B$—arc. We have hitherto not taken the inductance of this circuit into our calculation; this omission is permissible only to a certain extent. The circuit will always contain some inductance and will, consequently, always have a definite fundamental oscillation. The wave-length of this oscillation was about 420 m. in the tests from which the curves in Figure 3 are plotted.

The proof of the presence of these superfluous and, consequently detrimental oscillations of wave-lengths smaller than λ is:

(1) That the ratio $\frac{I}{I_0}$ between the arc radio frequency current and the arc direct current is larger than $\sqrt{\frac{1}{2}} = 0.7$, this being the value of the ratio when only one oscillation is present.[13] Figure 3 shows values of $\frac{I}{I_0}$ up to 0.9 and more; the arc radio frequency current I is therefore far from being a sine curve.

(2) The existence of oscillations of shorter wave-lengths than λ is evident also from the following observation:

During certain tests, a safety arrangement was inserted across the leads connecting the choke coils with the switchboard, the safety arrangement consisting of two sets of carbon filament lamps, each set in series with a condenser, the two condensers being connected to each other and to earth. When the capacity of C_1 was diminished, the lamps ceased glowing, or at any rate glowed very dimly, whereas the brilliancy increased with increasing C_1.

(3) A further proof is that $\frac{I_b}{I_a}$ is very much larger than what would be expected from formula (11); and this fact indicates especially that the fundamental oscillation of the shunt circuit, as mentioned above, is of great importance in this connection.

(4) That the statement in the latter part of (3) is correct is finally proven by the oscillographic analysis of the voltage of the arc as set forth below.

Oscillograms of the arc tension e_1 have been taken by means of the method previously employed by the author.[14] The oscillograms thus obtained showed the features indicated in Figure 4. Besides the normal peaks A (the extinction voltage) and B (the ignition voltage), a third peak C appeared, which latter, no doubt, is due to the arc current again decreasing to zero shortly after the ignition has taken place, or in any case decreasing to a very small value. That this is so is without doubt due to the free oscillations in the shunt circuit of the short wave-length λ_2, these oscillations being set up at the moment the discharge thru the arc commences anew. The corresponding current i'_1 is also plotted in Figure 4. The arc current is composed of the direct current (supply current) $I_o +$ the radio frequency current of wave-length λ and of the corresponding higher harmonics (the sum of these latter is shown as the dotted line ab in Figure 4) + the current i_1' of wave-length λ_2. The arc current i_1 resulting from all these currents is shown in Figure 4 and fully explains the reason for the appearance of the extra peak C.

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[13] P. O. Pedersen, previous citation, (a).

[14] P. O. Pedersen, previous citation, (a), page 285.

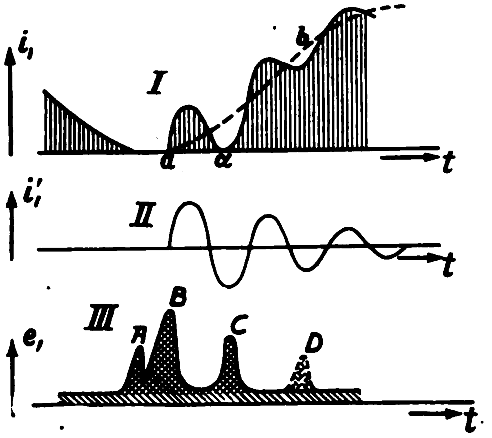

FIGURE 4

The above described course of the arc tension is the simplest one of those observed. Several peaks may appear as shown by D in Figure 4, III; also C may divide itself in two by analogy to A and B. This latter condition takes place if the current at a (Figure 4, I) remains zero for some time, because in this case another separate extinction voltage and ignition voltage are created.

Figure 5 shows one of the arc voltage oscillograms obtained.

We have now in the main explained the action of the diagram (Figure 2). This diagram may evidently be considered as a transformer arrangement, because the two circuits (1) arc $-Aa\,C_1C_2-$ arc and (2) arc $-Aa\,L\,Cc\,C_2-$ arc are coupled together by means of the arc and the series condenser C_2.

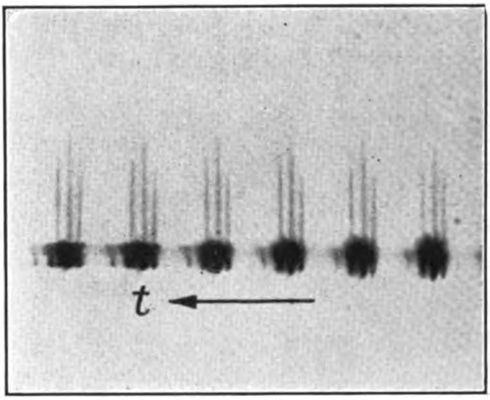

FIGURE 5

3. COMPARISON OF FIGURE 2 WITH THE SIMPLE DIAGRAM (WITHOUT THE SHUNT CONDENSER C_1)

It is evident from Figure 3 that the ratio $\frac{I_a}{I}$ between the antenna current and the arc radio frequency current may become somewhat larger than 1 by applying the arrangement shown in Figure 2. Some other effects, however, are introduced in connection therewith, which, at any rate, partly counteract the advantage in question. We will consider especially that:

1. The necessary direct current voltage across the arc increases very considerably.
2. The wave-length increases.

Tables 2, 3, and 4 below show this clearly.

TABLE 2

(Diagram and indications refer to Figure 2.) $C_1=13{,}800$ cm. (0.0153 μf.), $C_2=14{,}600$ cm. (0.0162 μf.), wave-length for $C_1=0$ is equal to 5,400 m.; $R=$ about 3 ohms; $P_o=I_oV_o$ is the energy supplied to the arc; C_1 is variable; and $(C_1=0)$ attached to any of the symbols means that the value of the latter is measured when $C_1=0$, that is, when the simple circuit connection, without the shunt condenser, is used.

1	2	3	4	5	6	7	8	9	10
C_1	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	I	I_a	I_b	λ	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{\frac{I_a^2}{P_o}}{\frac{I_a^2}{P_o(C_1=0)}}$
cm.			amps.	amps.	amps.	m.			
0	1.0	1.0	9.8	9.8	0	5,400	1.00	0.70	1.0
600	0.964	1.0	9.2	9.6	Small	5,500	1.033	0.68	1.03
2,400	0.857	1.29	9.2	10.2	2	5,660	1.11	0.767	0.982
5,600	0.714	1.61	9.4	10.8	6.5	5,900	1.15	0.94	1.06
7,600	0.750	1.61	9.3	11.6	7	5,980	1.245	0.885	1.17
10,350	0.672	1.73	9.4	12.2	8	6,100	1.298	1.00	1.33
13,250	0.693	1.77	9.2	12.7	8.6	6,160	1.38	0.95	1.37
25,750	0.571	2.03	7.1	4.5	6		0.635	0.89	0.187

The results of these measurements are partly represented by Figure 6. Curve *A* shows the figures of column 10 of Table 2; that is, the ratio $\frac{\eta}{\eta_0}$ between the apparent efficiency with shunt condenser and without the same. The curve shows that this ratio is a maximum for a value of C_1 between 12,000 and 14,000 cm. (0.0133 and 0.0156 μf.), further that the maximum η is about 1.37 η_0. It must, however, be noted that the wave-length increases simultaneously, as previously mentioned, and as shown by curve *D* in Figure 6. The increase of the wave-length in itself produces a higher efficiency; this increase amounts to about 1.12η, according to tests. The antenna current is, as previously mentioned, not quite a sine curve when the condenser C_1 is inserted, and this is especially the case for values of C_1 as large as 12,000 to 14,000 cm. (0.0133 to 0.0156 μf.) The antenna current in the ordinary arc circuit, for which $C_1 = 0$, is practically a sine curve when everything is properly adjusted. It is impossible to indicate definitely what fraction of the antenna current is due to "harmonics" of various kind. Three per cent. is very likely much too small a figure when $C_1 = 12,000$ cm. (0.0133 μf.). Curve *B*, Figure 5, is based upon the above corrections. It will be seen from this curve that the effective increased value of the efficiency η cannot be reckoned to be more than about $1.2\,\eta_0$.

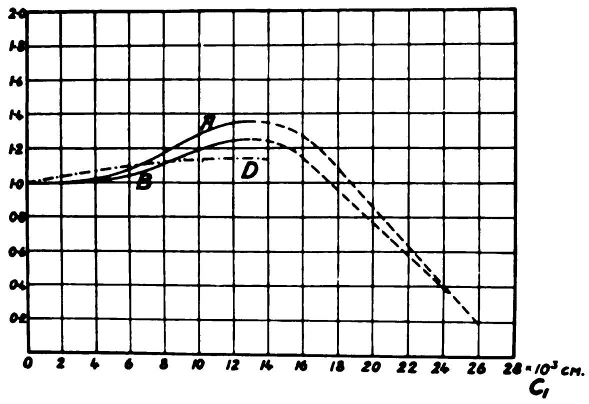

FIGURE 6

It might be that a more advantageous result could be obtained by choosing another ratio between the inductance and the capacity. In order to ascertain whether this be so or not, a series of tests were carried out (Table 3) in which the capacity of the condenser was kept constant, whereas the inductance was varied in such a way that the corresponding wave-lengths covered the range from 6,430 m. to 3,120 m. In no case were better results obtained than those shown in Table 2.

TABLE 3

(Data refer to Figure 2).

$C_1 = 13{,}800$ cm. (0.0153 μf.), $C_2 = 14{,}600$ cm. (0.0162 μf.), $R =$ about 3 ohms; $P_0 = I_0 V_0 =$ energy supplied to the arc. The inductance L is variable; L has the same value in each two related tests.

Tests were also carried out by varying the series condenser C_2, and a few of these tests are tabulated in Table 4. But none of these tests gave better results than the ones in Table 2.

TABLE 4

(Data refer to Figure 2)

$C_1 = 13{,}800$ cm. (0.0153 μf); $R = 1.6$ ohms; $P_0 = I_0 V_0$. The inductance in the first two tests was about 30 per cent. larger than in the two last tests.

We have thus, by applying the shunt circuit, been unable to increase η_0 to more than about 1.25 η_0. This increase in efficiency was, however, in all our tests accompanied by a considerable unsteadiness of the arc. It proved very difficult to keep the arc burning as steadily as desirable when C_1 has the large capacity necessary for increasing the efficiency by the abovementioned value. Furthermore, a good many frequencies are created—as set forth above—which are of no use at all, and might cause interference. We are, therefore, of the opinion that the advantages obtained by applying the shunt circuit are, as a whole, not of any great value. This, of course, does not exclude the possibility that the shunt circuit may be of advantage under certain other conditions of a special nature.

I wish to acknowledge my indebtedness to Messrs. J. P. Christensen, H. Erichsen, and A. Teglbjerg for the valuable assistance rendered during the above investigations.

Royal Technical College,
Copenhagen, February, 1920.

1	2	3	4	5	6	7	8	9	10
C_2	$\frac{I_o}{I_a(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	I	I_a	I_b	λ	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{\frac{I_a^2}{P_o}}{\frac{I_a^2}{P_o(C_1=0)}}$
cm.			amps.	amps.	amps.	m.			
12,000	0.674	2.15	9.6	12.2	8	6,430	1.27	1.01	1.03
0	1.0	1.0	10.0	10.0	0	5,610	1.00	0.709	1.0
12,000	0.738	1.89	9.5	13.9	8.2	6,140	1.465	0.913	1.39
0	1.0	1.0	10.0	10.0	0	5,360	1.00	0.709	1.0
12,000	0.686	2.04	9.6	14.0	8	5,840	1.46	0.99	1.35
0	1.0	1.0	10.2	10.2	0	5,140	1.00	0.714	1.0
12,000	0.653	2.29	10.1	14.0	9.2	5,160	1.385	1.03	1.19
0	1.0	1.0	10.5	10.5	0	4,730	1.00	0.70	1.0
12,000	0.715	2.09	9.7	13.8	8.2	4,430	1.425	0.898	1.16
0	1.0	1.0	10.5	10.5	0	3,890	1.00	0.696	1.0
12,000	0.734	1.88	10.0	12.6	9	3,610	1.26	0.95	1.11
0	1.0	1.0	10.2	10.2	0	3,120	1.00	0.713	1.0
12,000	0.662	2.29	9.9	14.1	7.8	6,400	1.425	1.03	1.23
0	1.0	1.0	10.3	10.3	0	5,640	1.60	0.71	1.0
12,000	0.667	2.04	10.7	14.0	15	3,620	1.31	1.07	1.31
0	1.0	1.0	10.5	10.5	0	3,180	1.00	0.70	1.0

1	2	3	4	5	6	7	8	9	10	11
C_2	C_1	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	I	I_a	I_b	λ	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{\frac{I_a^2}{P_o}}{\frac{I_a^2}{P_o(C_1=0)}}$
cm.	cm.			amps.	amps.	amps.	m.			
14,600	12,000	0.731	2.12	10.0	13.8	8.4	6,400	1.38	0.943	1.21
14,600	0	1.0	1.0	10.1	10.1	0	5,640	1.00	0.702	1.0
39,600	12,000	0.798	1.68	13.2	11.2	9.8	5,820	0.85	1.15	0.899
39,600	0	1.0	1.0	10.2	10.2	0	5,600	1.00	0.709	1.0

SUMMARY: A bibliography of oscillating arc investigations with coupled circuits is given. A special form of circuit, wherein the arc and the antenna circuit are coupled electrostatically thru an arc "series condenser," and a "shunt condenser," is studied analytically. Experimental results on the same circuit are given, and the practical usefulness of the circuit discussed.

DISCUSSION

Leonard F. Fuller (by letter): A preferred form of circuit in which C_2 of Professor Pedersen's Figure 2 is omitted and C_1, shunted directly across the arc terminals, is the only local condenser used, is shown in United States Patent 14,760, of November 25, 1919. This is a re-issue of my original patent number 1,179,353, and was used at Arlington and Tuckerton for some time. It increases antenna current about as effectively as the connection shown in Figure 2, and saves considerable equipment in a large station. Both circuits are only a means of improving an arc which is not operating under the best conditions and will cause no appreciable increase in the antenna current delivered by a well-designed arc operating with "tuned fields" in the proper atmosphere. For these reasons they have fallen into disuse in recent years.

It seems likely that the arc Professor Pedersen used in his experiments was operating with the air gap flux density, B_g, below the tuned value, for he states that "the increase of the wave length itself produces a higher efficiency." Such a change in efficiency is the natural consequence of operating an arc "underfield."

It would have been very helpful if the observations had been made with tuned fields, as arc performance data rarely permit of quantitative comparison if they are taken with untuned fields. A great amount of experimental work has had its value very seriously reduced by failure to appreciate this fact.

I heartily agree with the conclusion that circuits such as these are hardly worth while, but this is because of our present knowledge of tuned fields and the other factors effecting arc performance which enable us to accomplish the same desirable results in better ways and without fostering the harmonics mentioned by Professor Pedersen.

THE EQUIVALENT CIRCUIT OF THE VACUUM TUBE MODULATOR*

By

John R. Carson, Ph.D.

(Research Engineer, American Telephone and Telegraph Company, New York)

It is a well-known fact[1] that if an emf. E is impressed on the input terminals of the three-element vacuum tube amplifier of amplification constant μ and external or load impedance z, its behavior as an amplifier may be correctly described by postulating an emf. μE impressed on the load impedance z thru a resistance R_o, where R_o is the "internal resistance" of the tube and is given by the formula

$$\frac{1}{R_o} = \frac{\partial I}{\partial E_b} \tag{1}$$

Here I is the plate current, and E_b the steady plate-filament potential difference.

This law has led to the concept of the equivalent circuit of the vacuum tube amplifier, indicated schematically in Figure 1, which has proved a very valuable aid for interpreting the behavior of the device and in designing the associated circuits. The value of such a physical picture of the phenomena does not need

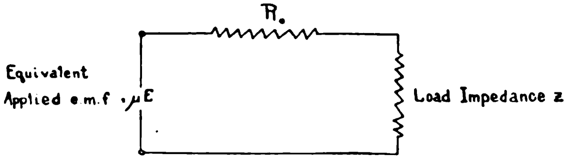

Figure 1—Equivalent Amplifier Circuit

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*Received by the Editor, April 30, 1920.

[1] The recognition of this valuable principle appears to be due to van der Bijl; see his papers: "Physical Review," September, 1918, and the Proceedings of The Institute of Radio Engineers, April, 1919. Strictly speaking, van der Bijl's statement of the law is limited to the case where the load impedance is a pure resistance; its extension to the case where the load impedance is unrestricted is however a very simple matter; see my paper in the Proceedings of The Institute of Radio Engineers, April, 1919.

to be pointed out to the engineer actually engaged in the development of the device and its simplicity as a working guide in interpreting and predicting results far outweighs the fact that it is necessarily incomplete and approximate only. On the other hand, in using such a physical conception, he will be wise to recognize clearly its limitations and guard against employing it under circumstances where it ceases to be a reliable guide.

The purpose of the present note is to point out the fact that the device when functioning as a modulator[2] may be represented by an "equivalent circuit" of almost equal simplicity, and the resulting physical conception may be used with considerable advantage and profit in interpreting the behavior of the device and in correctly designing the associated circuits for optimum performance. The equivalent modulator circuit may be inferred at once from the following theorem:

If a voltage E is impressed on the input terminals of a three-element vacuum tube feeding into a load impedance z, the operation of the device as a modulator may be correctly described by postulating an emf.

$$M\left(\frac{\mu R_o}{R_o+z} E\right)^2 \qquad (2)$$

impressed on the load impedance z thru a resistance R_o. M is the *modulation factor*, a physical parameter of the tube, and is given by the equation.

$$M=\left(\frac{1}{2R_o}\right) \cdot \left(\frac{\partial R_o}{\partial E_b}\right) \qquad (3)$$

The equivalent circuit is shown schematically in Figure 2.

The law formulated by this theorem and the character of the approximations involved are easily deduced from the treatment of the problem developed in my PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS' paper (April, 1919); the proof will be supplied in an appendix to the present note.

It should be remarked that the foregoing law and the equivalent modulator circuit to which it points are, of course, approximate only. It is important, however, to observe that the approximations underlying the concept of the equivalent modulator circuit are of precisely the same character and substantially the same order of magnitude as those involved in the equivalent amplifier circuit, which has proved so useful in the engineering development of the amplifier. This will be evident from the proof given in the appendix.

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[2] The following discussion applies equally well to the operation of the device as a detector in the arrangement where it functions by virtue of the curvature of the characteristic.

A simple problem will now be dealt with to illustrate the application of the concept of the equivalent modulator circuit in deducing certain principles which have a direct and important bearing on the design of the associated circuits.

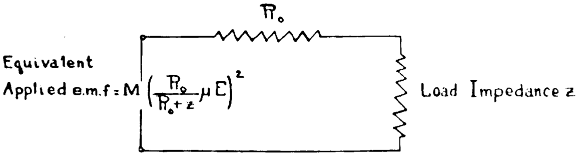

FIGURE 2—EQUIVALENT MODULATOR CIRCUIT

Let the impressed emf. E be the sum of two sinusoidal functions; thus

$$E = E_1 \sin p_1 t + E_2 \sin p_2 t \tag{4}$$

To fix our ideas, the first component of E may be regarded as the carrier wave and the second the signal wave. In substituting this expression for E in (2), to evaluate the fictitious emf. acting in the equivalent modulator circuit it is essential that E be written down as a complete real time function, since the operation of squaring is in effect a frequency transformation. From (4) we have:

$$\frac{\mu R_o}{R_o + z} E = \mu R_o \left(\frac{E_1}{Z(p_1)} \sin(p_1 t - \theta_1) + \frac{E_2}{Z(p_2)} \sin(p_2 t - \theta_2) \right) \tag{5}$$

where $Z\ (p_1)$ and $Z\ (p_2)$ are the absolute values of the impedance $R_o + z$ to currents of frequencies $p_1/2\pi$ and $p_2/2\pi$ respectively, and θ_1 and θ_2 are the corresponding phase angles. By aid of (5), formula (2) becomes after simplification and rearrangement

$$\begin{aligned} \frac{M}{2} \Big\{ & V_1^2 [1 - \cos(2 p_1 t - 2 \theta_1)] + V_2^2 [1 - \cos(2 p_2 t - 2 \theta_2)] \\ & + V_1 V_2 [\cos[(p_1 - p_2) t - (\theta_1 - \theta_2)] + \cos[(p_1 + p_2) t - \\ & (\theta_1 - \theta_2)] \Big\} \end{aligned} \tag{6}$$

where

$$V_1 = \frac{\mu R_o E_1}{Z(p_1)}$$

$$V_2 = \frac{\mu R_o E_2}{Z(p_2)}$$

This is the effective emf. acting in the equivalent modulator circuit and the current corresponding is calculated by usual methods. The modulated output current is evidently that corresponding to the term in $V_1 V_2$ of (6); it consists of the following two components

$$\frac{M}{2}(\mu R_o)^2 \frac{E_1 E_2}{Z(p_1)\cdot Z(p_2)}\cdot\frac{1}{Z(p_1-p_2)} \quad \text{of frequency} \quad \frac{(p_1-p_2)}{2\pi} \tag{7}$$

and

$$\frac{M}{2}(\mu R_o)^2 \frac{E_1 E_2}{Z(p_1)\cdot Z(p_2)}\cdot\frac{1}{Z(p_1+p_2)} \quad \text{of frequency} \quad \frac{(p_1+p_2)}{2\pi} \tag{8}$$

Now suppose that by a proper design the load impedance acts like a pure resistance R at the frequencies corresponding p_1, p_2, (p_1-p_2), and (p_1+p_2). Then the modulated currents are proportional to

$$\frac{R_o^2}{(R_o+R)^3}$$

and the modulated energy W_1 delivered to the load impedance is proportional to

$$\frac{RR_o^4}{(R_o+R)^6}$$

This expression is a maximum when $R=\frac{R_o}{5}$ and when this condition is satisfied becomes

$$\frac{\left(\frac{5}{6}\right)^6}{5R_o} \tag{9}$$

Now consider a second arrangement, where the load impedance acts like a pure resistance R at the frequencies corresponding to p_1, (p_1-p_2), and (p_1+p_2), but acts like a short circuit to currents of the signal frequency $\frac{p_2}{2\pi}$. This condition is substantially realizable at least when the carrier frequency is sufficiently large in comparison with the signal frequency. In this case the modulated currents are proportional to

$$\frac{R_o}{(R_o+R)^2}$$

and the modulated energy W_2 is proportional to

$$\frac{R\,R_o^2}{(R_o+R)^4}$$

This expression is a maximum when $R=\frac{R_o}{3}$, and when this condition is satisfied becomes

$$\frac{\left(\frac{3}{4}\right)^4}{3\,R_o} \qquad (10)$$

Comparison of (9) and (10) shows that for the same applied emf.'s, the modulated energy outputs W_1 and W_2 are related by

$$\frac{W_1}{W_2}=\left(\frac{3}{5}\right)\left(\frac{4}{3}\right)^4\left(\frac{5}{6}\right)^6=0.635$$

$$\text{or}\quad W_2=1.575\,W_1.$$

It follows at once that a proper design of associated circuits to satisfy the conditions laid down in the second case results in a gain of 57 per cent. in the available modulated energy as compared with the first arrangement. Another immediate deduction from formulas (7) and (8) is that, altho we are concerned only in transmitting radio frequency modulated currents, it is necessary to provide a low impedance path in the output circuit for the low frequency signal currents $\left(\frac{p_2}{2\pi}\right)$; otherwise a serious loss in the available modulated energy results.

The foregoing simple example has been worked thru to illustrate the application of the concept of the equivalent modulator circuit and to exhibit the utility from an engineering standpoint of a simple physical picture which, in its large outlines, is a faithful likeness of the actual phenomena.

APPENDIX

The deduction of the equivalent amplifier and equivalent modulator circuits follow from the general operational solution of the vacuum tube circuit problem as given in my paper in the April, 1919, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. Inasmuch as it will be impossible to repeat here the course of the argument it will be assumed that any reader who is interested in the problem will consult that paper for the details of the solution.

The method of solution is one of successive approximations. The output circuit current J and the potential difference v across the load impedance are written down as the expansions

$$J=J_1+J_2+J_3+\cdots \qquad (1)$$
$$v=v_1+v_2+v_3+\cdots$$

It is hen shown that the assumed expansions satisfy the conditions of the problem if the successive terms are related and defined by the scheme

$$\begin{aligned} J_1 &= P_1\,(\mu\, e+v_1) \\ J_2 &= P_1\, v_2+P_2\,(\mu\, e+v_1)^2 \\ J_3 &= P_1\, v_3+2\,P_2\,(\mu\, e+v_1)\, v_2+P_3\,(\mu\, e+v_1)^3 \end{aligned} \tag{2}$$

Here e (following the notation of the previous paper) is the emf. impressed on the input terminals, and P_1, P_2, P_3 are differential parameters of the tube which appear in the power series expansion.

$$J=P_1(\mu\, e+v)+P_2(\mu e+v)^2+\cdot\;\cdot\;\cdot$$

so that

$$\begin{aligned} P_1 &= \frac{1}{1\,!}\left(\frac{\partial I}{\partial E_b}\right) \\ P_2 &= \frac{1}{2\,!}\left(\frac{\partial^2 I}{\partial E_b{}^2}\right)=-\frac{1}{2}\,\frac{1}{R_o{}^2}\,\frac{\partial R_o}{\partial E_b}=\frac{M}{R_o} \end{aligned} \tag{3}$$

Now from (1), (2), and (3)

$$\begin{aligned} R_o\, J_1-v_1 &= \mu\, e \\ R_o\, J_2-v_2 &= R_o\, P_2\,(\mu\, e+v_1)^2 \\ &= M\,(\mu\, e+v_1)^2 \end{aligned} \tag{4}$$

Writing $v_1=-z\,J_1$ and $v_2=-z\,J_2$,—relations which follow at once from physical considerations,—equations (4) become

$$(R_o+z)\,J_1=\mu\, e \tag{5}$$

and

$$(R_o+z)\,J_2=M\left(\frac{R_o}{R_o+z}\,\mu\, e\right)^2 \tag{6}$$

Equation (5) is simply the equation for the current J_1 in a circuit of impedance R_o+z in response to the impressed emf. μe, and therefore, identifying J_1 with the amplification current, it leads at once to the law of the equivalent amplifier circuit. Similarly (6) is simply the equation for the current J_2 in a circuit of impedance R_o+z in response to the impressed emf.

$$M\left(\frac{R_o}{R_o+z}\cdot\mu\, e\right)^2$$

As shown in the paper, the component current J_2 is that which represents the modulated or detected output current; consequently equation (6) is simply a statement of the law of the equivalent modulator circuit.

It will be evident from the foregoing that the concepts of equivalent amplifier and modulator circuits are approximate, and that from a mathematical standpoint they represent simply first and second order approximations to infinite series. Experience, however, has shown that the convergence of the series is so rapid in the usual range of values occurring in practice as to make the deductions from these approximations useful engineering guides. Furthermore the mathematical theory enables us to recognize conditions where the approximations fail to be reliable and to make the necessary corrections under these circumstances.[3]

Department of Development and
Research, American Telephone
and Telegraph Company.

February 8, 1920.

SUMMARY: The author starts from the consideration of the equivalent circuit to a three-electrode vacuum tube *amplifier.* After pointing out the engineering usefulness of such an equivalent circuit, there is derived the equivalent circuit to a three-electrode vacuum tube *modulator.* The resulting theory is applied to a practical example in modulator design and its usefulness demonstrated.

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[3] Since the foregoing was written the writer's attention has been called to the fact that the law of the equivalent circuit of the vacuum tube amplifier was first published by Dr. John M. Miller, in the June, 1918, issue of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. The writer regrets that this had escaped his notice, and takes this opportunity of giving to Dr. Miller due credit for the first published recognition of this valuable principle

VACUUM TUBE AMPLIFIERS IN PARALLEL*

By
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(Western Electric Company, New York)

It is occasionally desirable to operate a number of vacuum tube amplifiers in parallel, that is, with all of their grids connected together and all of their plates connected together.

Very often the tubes are not uniform in their amplification constants and plate resistances. It is therefore of interest to express the effective values of these quantities for the group in terms of those for the individual tubes, and to compare the power output of the group with that of the tubes operated individually.

If we assume a straight line characteristic it is well known that for a single tube,

$$i = \frac{1}{r}(\mu e_g + e_p) \tag{1}$$

where e_g is an alternating emf. applied to the grid; e_p, the alternating plate voltage; i, the alternating plate current; μ, the amplification constant; and r, the internal alternating current plate circuit resistance.[1] If the external impedance in the plate circuit is Z, then

$$\left.\begin{aligned} e_p &= -Zi \\ \text{and} \qquad i &= \frac{\mu}{r+Z} e_g \end{aligned}\right\} \tag{2}$$

For n tubes in a common circuit, that is, the same e_g, e_p, and Z, the current in the output circuit can be expressed as

$$i = \frac{\bar{\mu}}{\bar{r}+Z} e_g \tag{3}$$

The problem is to evaluate $\bar{\mu}$ and $\bar{r}$ in terms of $\mu_1, \mu_2, \cdots \mu_n$ and $r_1, r_2, \cdots r_n$, the constants of the individual tubes. For any one tube

$$i_j = \frac{1}{r_j}(\mu_j e_g - Zi)$$

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* Received by the Editor, September 1, 1920.

[1] It is assumed that the frequencies are such that no account need be taken of the effect of internal capacities in the tube or of connecting leads.

since $e_p = -Z\bar{i}$.

Then
$$\bar{i} = \sum i_j = e_g \sum \frac{\mu_j}{r_j} - Z\bar{i} \sum \frac{1}{r_j}$$

Whence
$$\bar{i} = \frac{\dfrac{\sum \dfrac{\mu_j}{r_j}}{\sum \dfrac{1}{r_j}}}{\dfrac{1}{\sum \dfrac{1}{r_j}} + Z} e_g$$

Comparing with (3)
$$\bar{\mu} = \frac{\sum \dfrac{\mu_j}{r_j}}{\sum \dfrac{1}{r_j}} \tag{4}$$

and
$$\bar{r} = \frac{1}{\sum \dfrac{1}{r_j}} \tag{5}$$

It is at once evident that $\bar{r}$, the effective output resistance of the combination, is equal to the resistance of all of the tubes in parallel.

To arrive at a physical picture of $\bar{\mu}$, consider a single tube, constants μ_1, r_1, operating as a voltage amplifier with an external resistance r_o in its plate circuit. As is well known, the voltage developed across r_o is
$$r_o i_1 = \frac{r_o}{r_1 + r_o} \mu_1 e_g \tag{6}$$

(4) may be written
$$\bar{\mu} = \frac{\mu_1}{r_1 \sum \dfrac{1}{r_j}} + \frac{\mu_2}{r_2 \sum \dfrac{1}{r_j}} + \cdots + \frac{\mu_n}{r_n \sum \dfrac{1}{r_j}}$$

The first term may be written
$$\frac{\mu_1}{1 + r_1 \sum\limits_2^n \dfrac{1}{r_j}} = \frac{\dfrac{1}{\sum\limits_2^n \dfrac{1}{r_j}} \mu_1}{r_1 + \dfrac{1}{\sum\limits_2^n \dfrac{1}{r_j}}}$$

Comparing this with (6) we see that r_o is replaced by $\frac{1}{\sum_{2}^{n} \frac{1}{r_j}}$ which is the resistance of all the tubes except the first in parallel. We may, therefore, say that $\bar{\mu}$ is made up of the sum of n terms, each of which, when multiplied by e_g, represents the voltage which one of the n tubes would develop across an external resistance in its plate circuit equal to that of the remaining (n-1) tubes connected in parallel.

Certain special cases are of interest.

Let $\mu_1 = \mu_2 = \cdots = \mu_n = \mu$

Then $\bar{\mu} = \mu$

$$\bar{r} = \frac{1}{\sum \frac{1}{r_j}}$$

That is, if μ is the same for all the tubes, the effective value for the combination is the same as that of each tube. The effective resistance is still that of the individual resistances in parallel.

Again let the resistances be alike and the amplification constants different.

Putting $r_1 = r_2 = \cdots = r_n = r$

$$\bar{\mu} = \frac{1}{n} \sum \mu_j$$

$$\bar{r} = \frac{r}{n}$$

That is, the amplification constant of the group is the arithmetic mean of those of the individual tubes and the group resistance is that of a single tube divided by the number of tubes.

These equivalent constants furnish a basis for comparing the maximum power output per unit voltage input of the tubes as a group with the sum of their individual maximum outputs. This is equivalent to comparing the power output of the group of dissimilar tubes with that of a group of similar tubes each of which has a power output equal to the average of the individual outputs of the dissimilar tubes.

For this we shall take e_g as unity and assume that in each case Z is equal to the plate resistance of the tube or group of tubes in question. This is the condition for maximum power in Z. For a single tube this power is given by

$$p_j = \frac{\mu_j^2}{4 r_j} \tag{7}$$

and for the group

$$\bar{p} = \frac{\bar{\mu}^2}{4\,\bar{r}} \tag{8}$$

A measure of the relative efficiency of a group of *n* tubes is then given by the ratio

$$\rho = \frac{\bar{p}}{\sum p_j} \tag{9}$$

From (4), (5), and (8)

$$\bar{p} = \frac{\left(\sum \frac{\mu_j}{r_j}\right)^2}{4 \sum \frac{1}{r_j}} \tag{10}$$

Then

$$\rho = \frac{\left(\sum \frac{\mu_j}{r_j}\right)^2}{\left(\sum \frac{1}{r_j}\right)\left(\sum \frac{\mu_j^2}{r_j}\right)} \tag{11}$$

The conditions for making ρ a maximum are given by the $2n$ equations of the types

$$\frac{\partial \rho}{\partial \mu_j} = 0 \tag{12}$$

$$\frac{\partial \rho}{\partial r_j} = 0 \tag{13}$$

The equation

$$\frac{\partial \rho}{\partial \mu_1} = 0$$

reduces to

$$\mu_1 = \frac{\sum \frac{\mu_j^2}{r_j}}{\sum \frac{\mu_j}{r_j}}$$

From symmetry, it follows that the other equations of the type of (12) lead to the relation

$$\mu_1 = \mu_2 = \cdot \cdot \cdot = \mu_n$$

The equation

$$\frac{\partial \rho}{\partial r_1} = 0$$

reduces to

$$\left(\sum \frac{1}{r_j}\right)\left(\sum \frac{\mu_j}{r_j}\right)\mu_1^2 - 2\left(\sum \frac{1}{r_j}\right)\left(\sum \frac{\mu_j^2}{r_j}\right)\mu_1 + \left(\sum \frac{\mu_j}{r_j}\right)\left(\sum \frac{\mu_j^2}{r_j}\right) = 0.$$

The other equations of this type differ only in the subscript of μ, and hence from symmetry they can all be satisfied only if

$$\mu_1 = \mu_2 = \cdot \cdot \cdot = \mu_n.$$

Under these conditions

$$\rho = 1$$

regardless of the values of r_1, r_2, and so on.

We may conclude, therefore, that the total power that can be drawn from a group of tubes, per unit input voltage, is the same in a common circuit as in individual circuits when, and only when, the amplification constants of all the tubes are equal. When this condition is met it is not essential that the resistances be equal.

However, a very large fraction of the total power of the individual tubes is available when they are connected in parallel, even tho the tubes differ widely in amplification constant and internal resistance. To illustrate, two tubes the amplification constants of which are in the ratio of two to one, and the resistances of which are equal, give 0.90 as much power in a common circuit as they do in individual circuits. If, with the same ratio of amplification constants, the resistance of the first is twice that of the second, the power ratio is 0.89, and if the resistance of the first is half that of the second the ratio is 0.926.

Research Laboratories of the American
Telephone and Telegraph Company
and the Western Electric Company.

May 10, 1920.

SUMMARY: The general theory of the power output of a number of dissimilar vacuum tubes operated in parallel is given. The equations obtained are applied to the case when all the tubes have the same amplification constant, and also the case when the tubes all have the same internal resistance. Some practical examples are given.

DIGEST OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

GRANTED FEBRUARY 22, 1921—APRIL 12, 1921

BY

JOHN B. BRADY

(OURAY BUILDING, WASHINGTON, D. C.)

The object of this section of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS is to make available in convenient form for research engineers and others interested, brief information on the radio patents which are granted each week by the Patent Office. The rapid developments in this art emphasize the importance of radio research engineers being familiar with patent literature in order to eliminate as far as possible the duplication of research effort. It is not the purpose of this section to explain radio inventions fully, but merely to indicate the general nature of the patents in order that those of particular interest to individuals concerned with certain problems may be selected, and copies of the patents obtained for complete study. Copies of the complete patents may be obtained at ten cents each by addressing the Commissioner of Patents at Washington, D. C.

1,369,281—Oscar C. Roos, of Brooklyn, New York.
Electromagnetic-Wave-Transmitting System—Patented February 22, 1921.

This patent relates to a transmitting system in which an arc is shown as a source of sustained oscillations. The object of the invention is to provide a circuit for absorbing one or more of the higher harmonics of the fundamental of the antenna system so that the transmitted electromagnetic waves will have the frequency of such fundamental and will be substantially simple harmonic. Parallel branch circuits are provided adapted to absorb the undesirable or parasitic frequencies, while the remaining oscillations are transmitted as electromagnetic waves. The branch circuits are arranged to rectify the absorbed oscillating energy and return it to the generator circuit to assist in feeding the arc.

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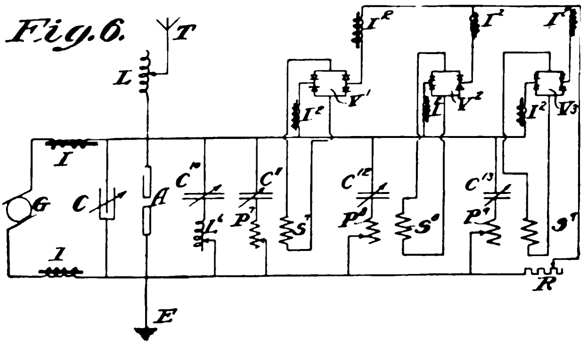
*Received by the Editor, April 25, 1921. While great care has been taken in the preparation of these Digests, THE INSTITUTE OF RADIO ENGINEERS assumes no responsibility for their correctness or completeness, or for possible omissions of particular patents.—EDITOR.

Fig. 6.



NUMBER 1,369,281—Electromagnetic-Wave-Transmitting System

1,370,093—George B. Crouse and Isaac H. Mills, of Brooklyn, New York, Assignors to the Sperry Gyroscope Company, of Brooklyn, New York, a corporation of New York. Receiving-Panel—Patented March 1, 1921.

Fig. 3.

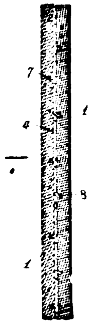
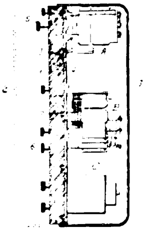


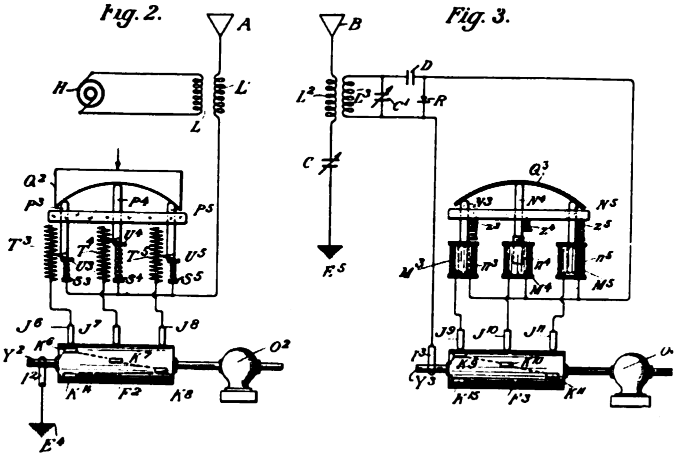
Fig. 1.



NUMBER 1,370,093—Receiving-Panel

This patent relates to a construction of panel for mounting radio apparatus. The panel is made up of insulating material and a metallic shield embedded therein which forms a barrier to stray magnetic and electrostatic fields which might affect radio apparatus supported and enclosed by the panel.

1,370,504—John Hays Hammond, Jr., of Gloucester, Mass.
Telestereotypy—Patented March 1, 1921.



NUMBER 1,370,504—Telestereotypy

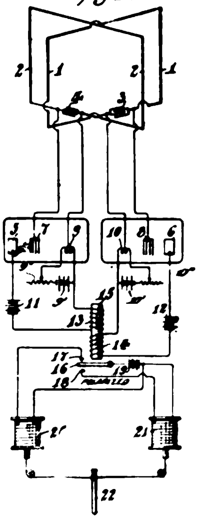
This patent is directed to a system for transmitting and reproducing forms and shapes of objects and solids at a distance by radio transmission. The transmitter is energized by a suitable source of oscillations and an apparatus connected in circuit with the antenna for successively varying the amplitude of the oscillations in accordance with the shape of the object at the transmitter station. The receiving station contains an apparatus synchronized with the apparatus of the transmitter whereby the variation in amplitude of the received oscillations cause a reproduction of the shape of the object at the distant station.

1,370,688—John Hays Hammond, Jr., of Gloucester, Mass.
System of Radio-control—Patented March 8, 1921.

This patent relates to a system for controlling a torpedo, a boat, or aircraft by radio. Two loop antenna, arranged in different planes are employed, each connected to separate vacuum tube detectors which mutually control a relay which is connected to regulate the position of the steering gear.

1,370,735—Charles Samuel Franklin, of London, England, Assignor to Radio Corporation of America, of New York, N. Y., a corporation of Delaware.

Fig.1.



Number 1,370,688—System of Radio-control

Aerial System for Wireless Signaling—Patented March 8, 1921.

Fig 1

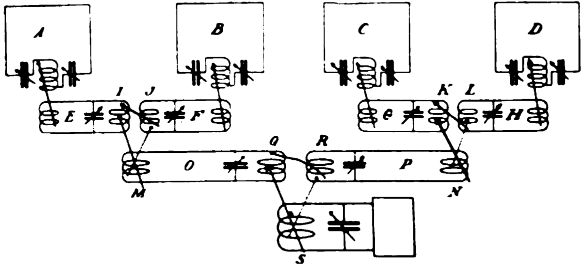
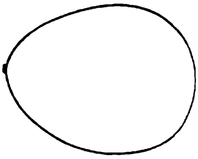


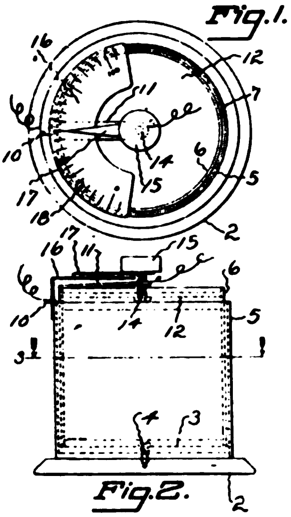
Fig. 3



Number 1,370,735—Aerial System for Wireless Signaling

The object of this invention is to secure a more complete cancellation of signals in a direction opposite to that in which reception is desired. A plurality of antennas are employed, each separated a fraction of a wave length, and circuits arranged for combining the antennas to secure a plurality of directional systems. The systems are effectively separated a fraction of a wave length and the energy superimposed upon a common receiver. The patentee points out that the resulting polar curve for the combined systems is much better than can be obtained from each system alone. The curve is sharper in the direction toward the distant transmitting station and gives nearly complete cancellation in all directions, both vertically and horizontally, at the back of the station.

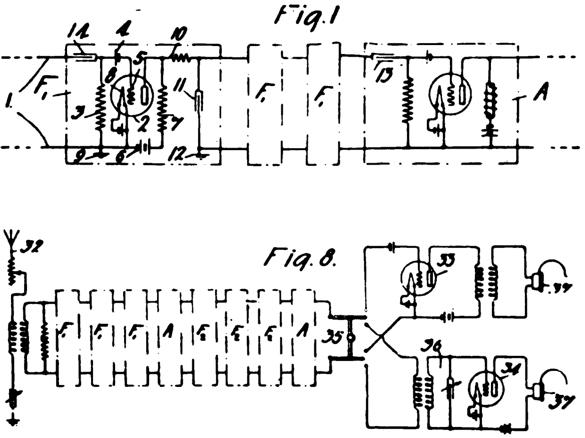
1,371,061—Clarence D. Tuska, of Hartford, Connecticut.
Condenser—Patented March 8, 1921.



Number 1,371,061—Condenser

This patent relates to a form of variable receiving condenser made up of paper stock and metal foil.

1,371,228—Austen M. Curtis, of Brooklyn, N. Y., Assignor to Western Electric Company, Incorporated, of New York, N. Y., a corporation of New York.
Reduction of Static Interference in Radio Receiving Stations—Patented March 15, 1921.



Number 1,371,228—Reduction of Static Interference in Radio Receiving Stations

This invention relates to a wave filter for use in radio receiving systems for the purpose of reducing the effect of static or atmospheric disturbances.

1,371,567—Robert H. Marriott, of Bremerton, Washington.
Radio Receiving System—Patented March 15, 1921.

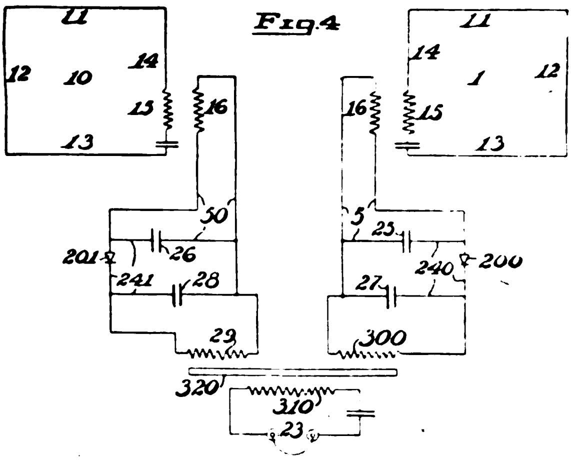


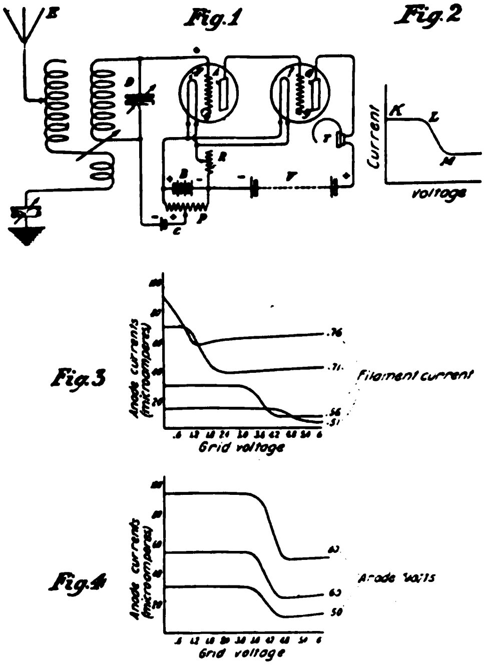
Fig. 4

Number 1,371,567—Radio Receiving System

This invention relates to a receiving circuit designed to dissipate or neutralize undesirable disturbing currents. A plurality of receiving circuits are employed connected to a neutralizing circuit and a circuit which contains rectifiers acting as frequency changing devices.

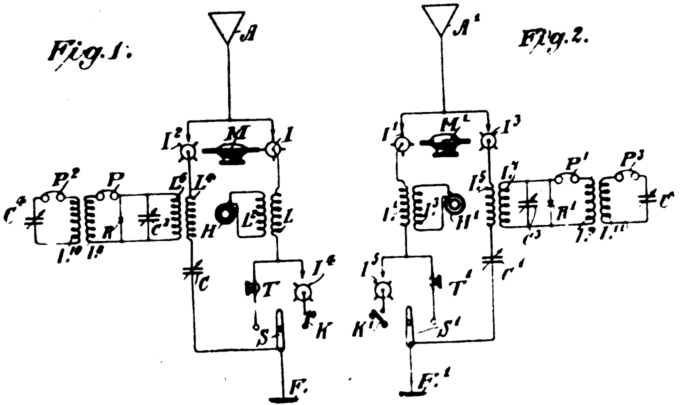
1,371,757—Ernest Walter Brudenell Gill, of Oxford, England, Assignor to Radio Corporation of America, of New York, N. Y., a corporation of Delaware.
Wireless-Telegraph Receiver—Patented March 15, 1921.

This patent pertains to a circuit arrangement for vacuum tube receivers wherein the voltage of the first grid is adjusted so that the current in the plate circuit of the second tube may decrease as the voltage of the first grid increases and increase as the voltage of the first grid decreases. The plate current of the second tube varies inversely with the potential of the grid of the first tube thru a portion of a cycle. The purpose of this arrangement is to obtain a response of equal strength for all signals over a particular strength and to provide more marked discrimination between signals received from different types of transmitters such as Telefunken and British Navy spark sets.



Number 1,371,757—Wireless-Telegraph Receiver

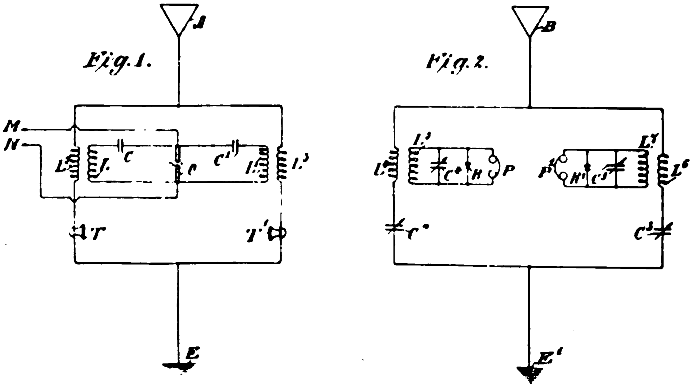
1,372,425—John Hays Hammond, Jr., of Gloucester, Mass. System of Radio Telegraphy and Telephony—Patented March 22, 1921.



Number 1,372,425—System of Radio Telegraphy and Telephony

This invention relates to a system for simultaneously transmitting and receiving in radio telegraphy and telephony. The invention further contemplates the reduction in interference of two transmitting stations in the same neighborhood. The principle involved is that the antenna of each station is simultaneously connected with the transmitter of that station, and the receivers at this same instant are disconnected, so that neither station receives during the instant that either transmitter is connected for operation.

1,372,426—John Hays Hammond, Jr., of Gloucester, Mass.
Multiplex Radiotelephony—Patented March 22, 1921.

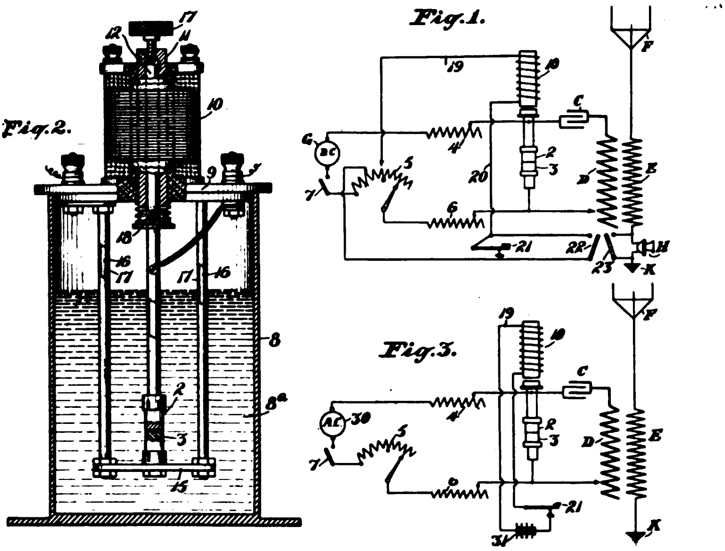


Number 1,372,426—Multiplex Radiotelephony

This patent relates to a system for transmitting and receiving two or more radio telephone conversations simultaneously. Figure 1 represents a transmitting station wherein two conversations may be transmitted on different wave lengths and Figure 2 shows a corresponding receiving station wherein the conversations may be received on different wave lengths.

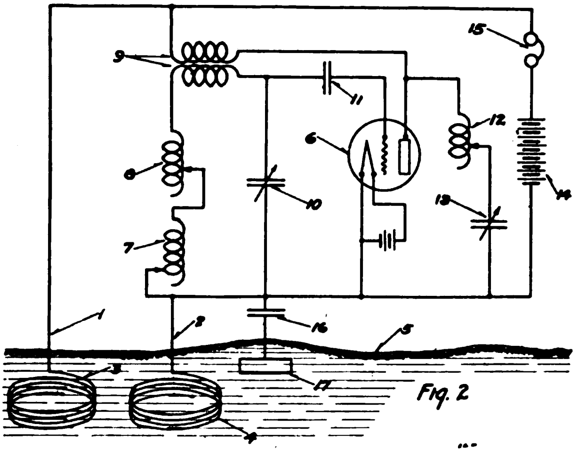
1,372,808—Alphonsus L. Golden, of Oakland, California, Assignor to National Radio Company, of San Francisco, California, a corporation of Arizona.
Apparatus for the Production of Intermittent or Continuous High-frequency Oscillations—Patented March 29, 1921.

This patent shows a construction of oscillator comprising a spark gap having electrodes submerged in distilled water. The oscillator may be arranged in circuit for telegraphy or telephony forming a continuous arc when employed for telephonic conversations and an intermittent make and break when used in telegraphing.



Number 1,372,808—Apparatus for the Production of Intermittent or Continuous High-frequency Oscillations

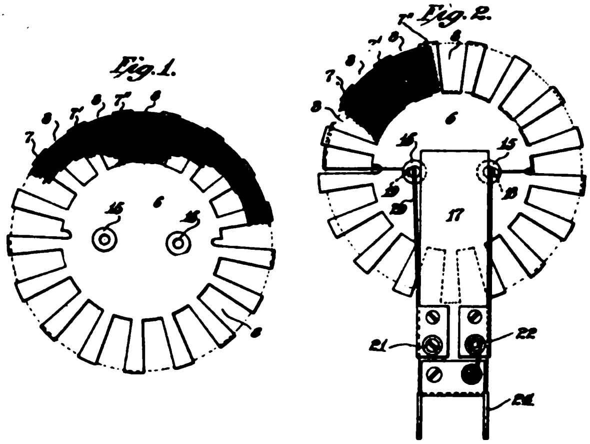
1,372,658—Edward Thomas Jones, of New Orleans, Louisiana. Underground or Underwater Antenna System—Patented March 22, 1921.



Number 1,372,658—Underground or Underwater Antenna System

This patent shows an underground or underwater antenna system comprising a pair of concentrated free ended coils of insulated cable which are submerged in water, or buried in the ground a relatively short distance apart and connected to receiving apparatus.

1,372,850—Eugene T. Turney, of New York, N. Y.
Inductance Device—Patented March 29, 1921.



NUMBER 1,372,850—Inductance Device

This invention relates to a construction of inductance formed by a winding on a flat disc with radiating arms. The wire is wound spirally on the flat arms.

1,373,504—Harry W. Hitchcock, of New York, N. Y., Assignor to American Telephone and Telegraph Company, a corporation of New York.
Electrical Measuring Apparatus—Patented April 5, 1921.

This patent relates to an arrangement for variable condensers in which a fixed capacity is adapted to be connected in parallel with any desired portion of the variable capacity. By this circuit arrangement the desired maximum capacity and also the desired intermediate capacities between the minimum of the variable condenser and the maximum of the two condensers in parallel may be obtained.

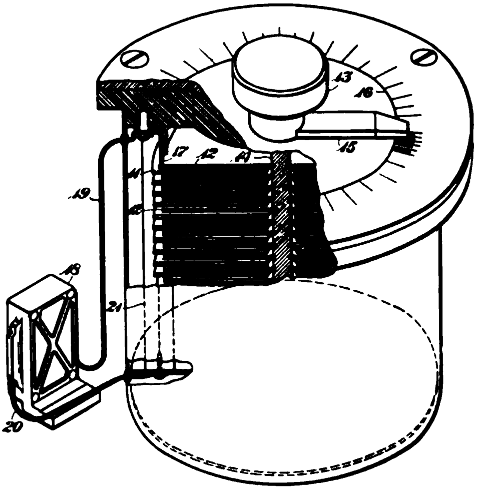


Fig. 1

Number 1,373,504—Electrical Measuring Apparatus

1,373,612—Earl C. Hanson, of Washington, District of Columbia
Underground Loop-Antenna—Patented April 5, 1921.

Fig.1.

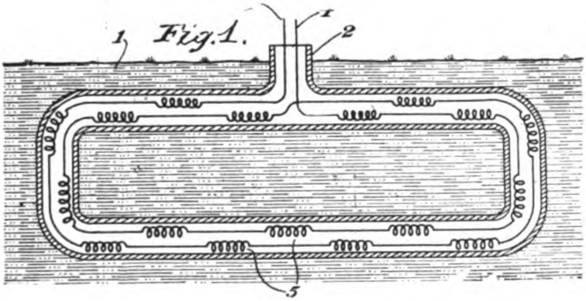
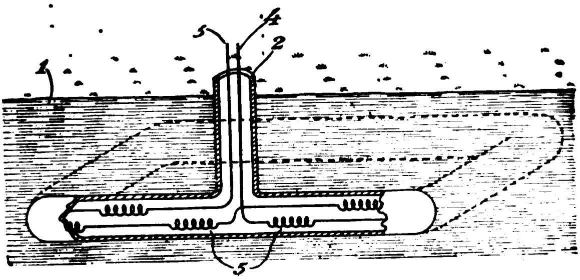


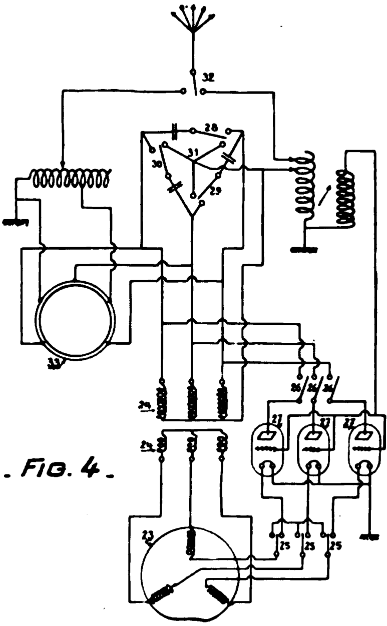
Fig. 2



Number 1,373,612—Underground Loop-Antenna

This patent shows an underground antenna system for radio signaling in which a looped coil is enclosed in a conduit and buried beneath the earth. The coil is provided with filter coils at intervals in the turns in the loop for the purpose of reducing response to shock impulses.

1,373,710—Victor Joseph Francois Bouchardon, of Lyons, France. Generator of High-frequency Oscillations for Wireless Telegraphy—Patented April 5, 1921.

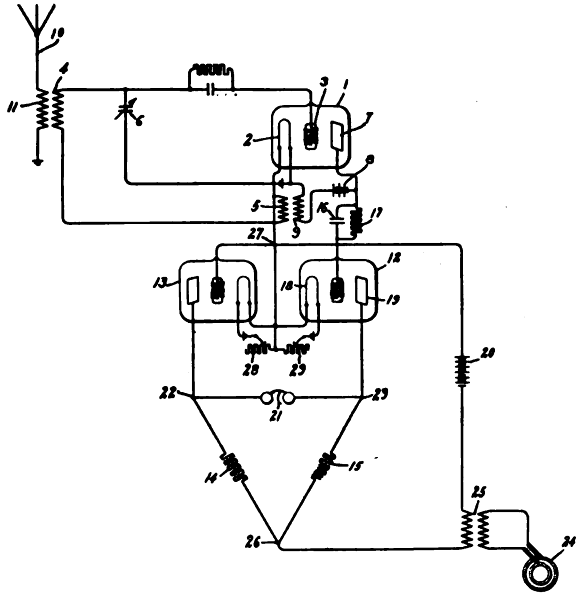


- FIG. 4 -

NUMBER 1,373,710—Generator of High-frequency Oscillations for Wireless Telegraphy

This patent relates to a transmitter in which a rotary spark gap set or a continuous wave vacuum tube generator set may be employed. Three phase supply is employed to energize the vacuum tube set wherein three tubes are shown star connected to form an oscillating circuit.

1,373,931—Ernst F. W. Alexanderson, of Schenectady, New York, Assignor to General Electric Company, a corporation of New York.
Radio Receiving System—Patented April 5, 1921.

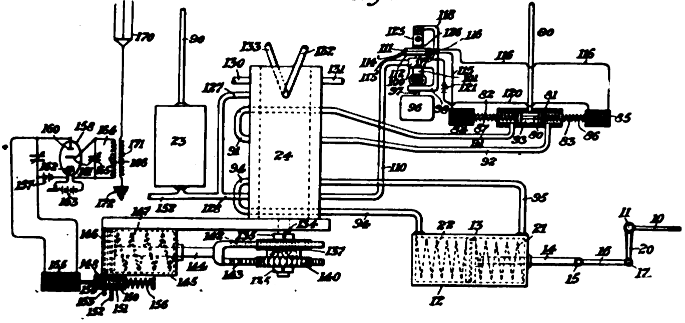


NUMBER 1,373,931—Radio Receiving System

This patent relates to a receiving circuit in which a radio frequency oscillator at the receiving station is adjusted to be normally inoperative. It is arranged so that when signals of a desired frequency are received in the system the local oscillator will be set into operation and produce oscillations of the same frequency as the signaling oscillations.

1,374,124—Albert D. Trenor, of New York, N. Y., Assignor to John Hays Hammond, Jr., of Gloucester, Mass.
System for the Control of Dirigible Devices from a Distance —Patented April 5, 1921.

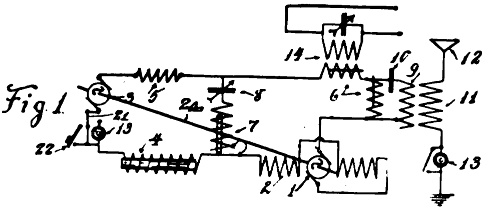
Fig. 1



NUMBER 1,374,124—System for the Control of Dirigible Devices from a Distance

This patent relates to a system of engine valve control by the reception of radiant energy. The valve mechanism is arranged for distribution of motive fluid to a plurality of different actuating devices.

1,374,170—August J. Kloneck, of New York, N. Y.
Generating System for Electric Currents—Patented April 5, 1921.



NUMBER 1,374,170—Generating System for Electric Currents

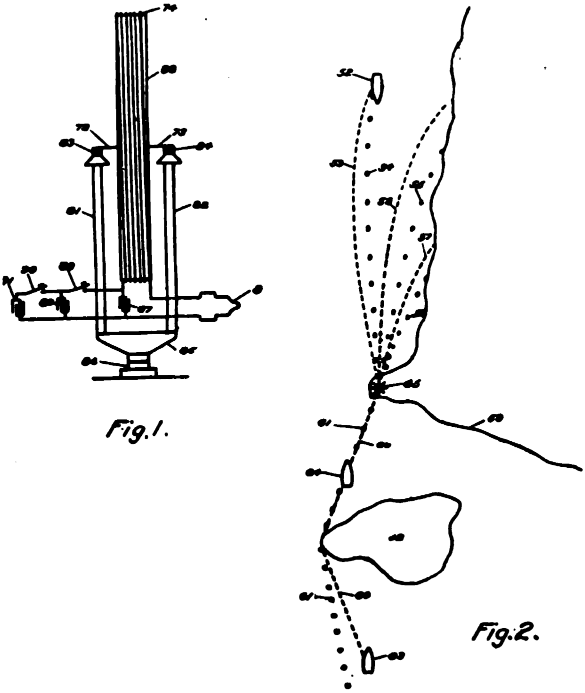
This patent relates to a generating system for radio frequency currents, and shows a circuit arrangement for a radio transmitting station.

1,374,293—Reginald A. Fessenden, of Chestnut Hill, Mass.
Wireless Direction-Finder—Patented April 12, 1921.

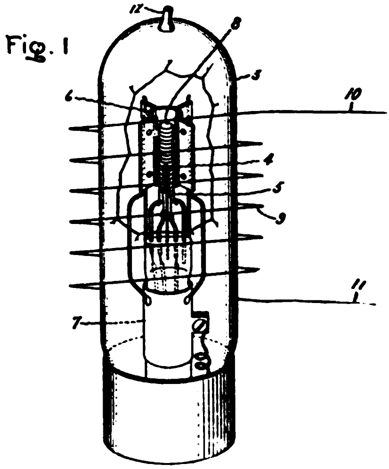
This invention relates to a method of determining the direction of signals from a receiving station. The method consists in taking a plurality of observations at the observing station at different wave frequencies transmitted from the radiating station and noting the amount of the discrepancies between the observations thereby determining the amount of wave bending to obtain the true direction of the radiating station from the observing station.

1,374,679—John B. Pratt, of Schenectady, New York, Assignor to General Electric Company, a corporation of New York.
Degasifying Process—Patented April 12, 1921.

This patent pertains to the pre-treatment of thermionic vacuum tubes during the process of manufacture. Gas is removed from the electrodes by a method of heating the metallic masses to an elevated temperature by electric induction. By driving out the gases from the conductive parts, the later slow evolution of gases is substantially reduced. A radio frequency magnetic field is employed to produce the induced heating current.

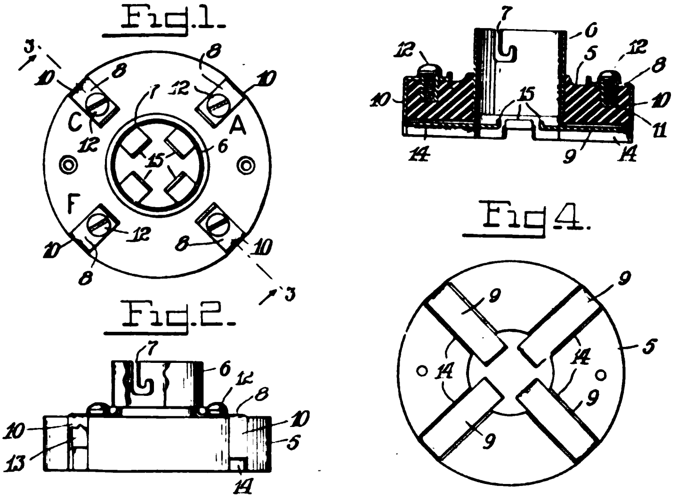


NUMBER 1,374,293—Wireless Direction-Finder



NUMBER 1,374,679—Degasifying Process

1,374,832—Harold Potter Doule, of Meriden, Connecticut. Assignor to the Connecticut Telephone and Electric Co., Inc., of Meriden, Connecticut, a corporation of Connecticut Vacuum-Tube Base—Patented April 12, 1921.



Number 1,374,832—Vacuum-Tube Base

This patent shows a socket for a thermionic vacuum tube.

PROCEEDINGS OF
The Institute of Radio Engineers

Volume 9 AUGUST, 1921 Number 4

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PILOTING VESSELS BY ELECTRICALLY ENERGIZED CABLES*

By

A. Crossley

(Expert Radio Aid, Navy Department, Washington, D. C.)

Piloting vessels by means of cables energized by audio frequency currents is the result of the work of many scientists, inventors, and engineers, each having contributed some part to the general scheme whereby it is possible at this date successfully to apply the system for piloting vessels thru treacherous channels during inclement weather.

Before entering into a discussion on the general details of this system, there will be given a brief history of the evolution of the system. This history is the result of a thoro investigation of the prior art. The writer does not wish to be quoted officially as to the authenticity of statements made should it be proven later that there are other inventors who claim priority on the hereinafter stated inventions. The writer, therefore, does not desire to cover the system from a patent standpoint, but only desires to bring to the attention of those interested the technical details, and also the possibilities of this new aid to navigation.

General History

A résumé of the past history of the evolution of the Audio Piloting System may be briefly stated as follows:

Michael Faraday discovered in 1851 the principle of electromagnetic induction.

Alexander Graham Bell's invention of the telephone receiver in 1876.

A. R. Sennett's British patent, number 13,415, of 1892, which discloses means of maintaining communication with light vessels by use of a submerged cable from which signals were received on board lightship by means of a multiple turn loop and telephone receivers.

Charles A. Stevenson's British patent, number 5,498, of

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*Received by the Editor, November 8, 1920. Presented before The Institute of Radio Engineers, New York, March 2, 1921.

1892, which discloses means for navigating vessels over electrically-energized cables and which shows the use of conduction principle at the receiving end in connection with sensitive galvanometer for recording purposes.

Robert B. Owens' American patent, number 736,432, of 1903, which shows a combination of the Stevenson's cable and Sennett's receiving apparatus in conjunction with special method of tilting receiving coils with respect to cable.

Alexander Chessin's British patent, number 21,610, of 1912, which shows an improvement on Owens' patent with reference to a means of mechanically tilting receiving coils.

July, 1916, issue of "Motor Boating," and also the August, 1916, issue of "Popular Mechanics," in which Earl C. Hanson discloses information on application of vacuum tube amplifier to audio frequency circuits, among which is the proposed use of such a system for piloting vessels thru fogs.

Earl C. Hanson's American patent, number 1,315,197, of 1919, which discloses application of vacuum tube amplifier to audio frequency receiving circuits.

Further work on the application of the amplifier to the Audio Piloting System has been, it is understood, undertaken by the English and German Navies, but full details on this work are not known to the writer.

Expert Radio Aid R. H. Marriott, of the Puget Sound Navy Yard conducted a series of interesting experiments at that place using the same circuits that Hanson had previously employed. Marriott brought to the attention of the Navy Department the results of his tests, and partly thru his efforts the Navy Department decided to make a thoro investigation of the merits of the system.

Having outlined previous work attempted, we will now devote our attention to the experimental work undertaken by the Bureau of Engineering, Navy Department, to determine the feasibility of developing and applying this system for Naval use.

NEW LONDON EXPERIMENTS

Upon receipt of orders from Commander S. C. Hooper, in charge of Radio Division, Bureau of Engineering, the writer proceeded to the Submarine Case, New London, Connecticut, on October 18, 1919, to conduct preliminary experiments. Arrangements were made whereby a sixty-foot (18.3 m.) sailing launch was placed at his disposal for the experiments. A 5,250 foot (1,600 m.) length of 9,000 circular mil (0.076 cm. diameter) single conductor (Navy Standard) rubber insulated cable was submerged in the channel of the Thames River from the Submarine Base to a point approximately 5,000 feet (1,520 m.) down the river. The extreme end of this cable was grounded to a six foot (1.8 m.) length of 1.5 inch (3.8 cm.) galvanized iron pipe while the shore end of the cable was connected thru a lamp bank of eight 32-candle-power carbon lamps to a 0.5 kilowatt 500 cycle generator on board the submarine "N-4," and grounded to the hull of the submarine. The cable was anchored at 500 foot (152 m.) intervals along the course, but due to the difficulty experienced in handling the sailing launch, this cable was not laid in a straight course.

The receiving equipment consisted of two coils wound on a wooden frame four feet (1.2 m.) square, each coil having 240 turns of number 20 single cotton covered copper wire,* a double pole double throw switch and type SE-1,600 Navy two stage audio frequency amplifier, to which were connected standard telephone receivers. The double pole double throw switch made it possible to connect either coil to the amplifier, and thereby compare the relative received signal strength of the respective coils. A 0.0025 microfarad variable air condenser was connected in series with the input terminals of the amplifier as shown in Figure 1, with a view towards tuning the circuit to resonance; but because of the low inductance of the coil this was not possible, and the condenser was removed from the circuit.

A current flow of 2.3 amperes at 170 volts was supplied to the submerged cable. The input watts as recorded on a wattmeter indicated that the input in the cable was 145 watts or a power factor of 0.37. The poor power factor obtained was due to the fact that it was not convenient to obtain direct leads from the generator without totally dismantling the panel of the radio set of which the generator was a part, and therefore resort was made to connecting the primary of the transformer in series with the cable, thus creating a predominance of inductance in the circuit with the resultant lagging power factor. The receiving apparatus was installed on the sailing launch, one coil on one side, and the other coil on the opposite side of the launch above the water line. The launch was then made to follow a zigzag course over the cable to note the relative signal strength as received from the cable by the respective coils. It was noted that there was no shielding effect between the two coils and resort was made to the use of one coil. Using the single coil in the vertical position it was possible to tell within a distance of ten feet (3 m.) the exact location of the cable. The signal received from the cable was of an audibility in excess of 10,000 when the launch was directly over the cable, and of such intensity to be uncomfortable to retain telephone receivers on the observers' ears, while when moving away from the cable the signal strength rapidly diminished until it became inaudible at a distance of 600 feet (180 m.) from the cable.

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* Diameter of No. 20 wire = 0.032 in. = 0.082 cm.

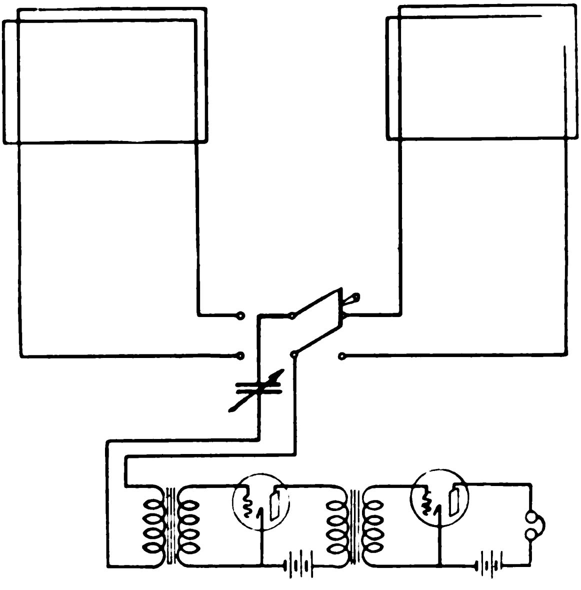
SE-1600 2 STEP AMPLIFIER

FIGURE 1

The next experiment consisted of turning the coil at different angles to the vertical plane to note whether a pronounced maximum or minimum signal could be obtained from the cable. It was noted, as expected, that a maximum signal was obtained when the plane of the coil was in line with the cable, and a minimum signal was obtained when the coil was at right angles to the plane of the cable.

Having proved that the single coil could be used to advantage on wooden vessels, arrangements were made with Capt. Oliver of the Submarine Base, whereby the Submarine "G-1" was detailed for work to prove whether or not a shielding effect was present when a steel hull was interposed between the coils.

The results of experiments conducted on the "G-1" proved that there was a shielding effect between the coils and by use of this effect the Commander of the "G-1" could easily note on which side of the submarine the cable was situated. Strongest signal was always picked up by the coil nearest the cable, while minimum signal was received by the coil which was furthest from the cable. The shielding effect was not as pronounced as it should have been, but this was probably due to the poor shielding effect of the sloping sides and small conning tower of the "G-1."

On sailing down the river and passing over end of cable, it was immediately noted that the submarine had passed over the cable by the sudden decrease in signal strength. This decrease in signal strength was much more pronounced than the decrease noted when passing over and away from cable on a course at right angles to cable. No difference was noted in signal strength when the submarine was at different points along the cable, therefore showing that the attenuation effect along the cable could be neglected from a practical operating standpoint.

Having concluded necessary preliminary experiments at New London, the writer returned to Washington and recommended to the Bureau of Engineering that this system be further investigated wherein resort could be made to the use of a vessel having steel hull with a high superstructure, and that experiments be conducted under conditions which would be representative of its future practical application. Upon receipt of recommendations thus submitted, Commander Hooper decided that New York Harbor would be an ideal place to complete the final experiments.

NEW YORK EXPERIMENTS

Immediately after the decision to conduct further experiments at New York, the writer proceeded to the Navy Yard, New York, conferred with Commander R. F. McConnell, and made arrangements for the future experimental work. The New York Yard then obtained the services of the Mine Planter "Ord" and laid a cable from the Bayview Naval Station to a point approximately 700 feet (210 m.) from the Ambrose Channel Light Vessel. The cable referred to above consisted of 2,000 feet (610 m.) of 9,000 circular mil (0.076 cm. diameter) lead and armored cable, 2,000 feet (610 m.) 9,000 circular mil lead covered cable, and 83,000 feet (25,300 m.) 9,000 circular mil rubber insulated Navy Standard cable. This cable was anchored at 500 foot (152 m.) intervals with concrete anchors of similar design to the anchor shown in Figure 2, and was laid as close as possible to the center of Ambrose Channel. The extreme end of the cable was grounded to a two foot (0.61 m.) square copper plate while the shore end was connected thru an inductance to a relay key which was actuated by an "Omnigraph" transmitter; and from this key, connection was made to one terminal of a 0.5 kilowatt 500 cycle generator; the other terminal of the generator was grounded to a copper plate two feet (0.61 m.) square, which was submerged in the bay.

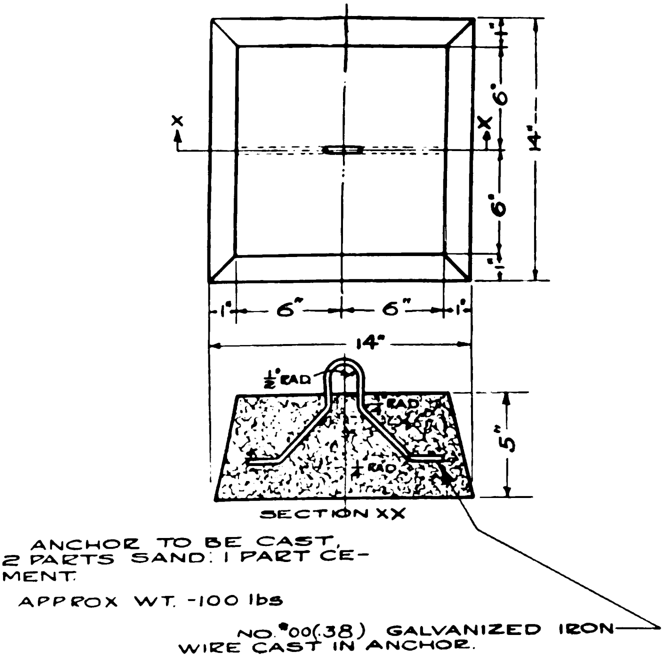
X
X
1"
6"
6"
1"
14"
1"
6"
6"
1"
14"
½" RAD
RAD
RAD
5"
SECTION XX
ANCHOR TO BE CAST, 2 PARTS SAND: 1 PART CEMENT.
APPROX WT. -100 lbs
NO. #00(.38) GALVANIZED IRON WIRE CAST IN ANCHOR.

FIGURE 2

The destroyer "O'Brien" was detailed to assist the New York Yard in this work and was equipped with two collector coils, four feet (1.22 m.) square, having 240 turns of number 20 double cotton covered wire,* one coil suspended over one side of the vessel and the other coil over the opposite side. Leads from these coils were led to a double pole, double throw switch on the bridge, this switch being connected to a Type SE-1,600 two-stage audio frequency amplifier with the usual telephone receivers. Leads from the coils to the switch were run in lead and armored cable to prevent these leads from picking up extra signal from the cable and induction from ship's circuits.

---

* Diameter of number 20 wire = 0.032 in. = 0.082 cm.

A current flow of seven amperes was delivered to cable. The "O'Brien" steered a course from Bay Ridge out the Channel towards the Light Vessel, but lost the signals from the cable when passing a point 1,000 feet (300 m.) from the shore end. Upon noting that no current was being delivered to the cable from the 1,000 foot (300 m.) point to the Light Vessel, a sailing launch was obtained and the cable was under-run and found to be broken at the 1,000 foot (300 m.) point. The broken section of the cable was repaired, but on further investigation covering a period of three months it was found that the cable had been broken in fifty-two different places, and was of no further use. This investigation was carried on during midwinter and was extremely trying to the personnel engaged in this work. It is believed the breaks in the cable were caused by strain put upon it while being laid.

During the period when investigation of the defects in the cable was being conducted, the New York Yard was requested to try different types of cable to note which type would be best suited for this system. This was the original idea when the three different sections of cable were incorporated in the first cable, but as it was not possible to obtain this information due to the defective nature of this cable, experiments were conducted in the Navy Yard to solve this problem. Three cables, one 9,000 circular mils (0.076 cm. diameter) lead and armored, one lead covered 9,000 circular mils, and the other the rubber insulated 9,000 circular mils cable of 150 foot (45 m.) lengths were submerged to the same depths in the East River near Pier H, in the Navy Yard. Each cable was grounded at one end to a copper plate and the other end was connected to a 0.5 kilowatt 500 cycle generator. A current flow of one and one-half amperes was supplied at different intervals to the three cables; and the audibility of the received signal as received by a 240 turn four foot (1.2 m.) coil, a type SE-1,600 amplifier with the usual telephone and audibility meter, from the respective cables, was noted. The audibilities obtained were as follows:

Cables	*Audibility*
Lead and armored	1,000
Lead covered	1,000
Rubber covered	700

The results of the above-mentioned tests being in harmony with the practical design of future cables, work was immediately started on the design of a standard type cable. After consultation with certain cable manufacturers, specifications were drawn up for the purchase of 87,000 feet (27,000 m.) of the special cable shown in Figure 3. This cable consists of seven strands number 16 tinned copper wire,* a layer of 30 percent. Para rubber 0.188 inch (0.476 cm.) thick, one layer of cambric, a layer of jute and an armor of number 12 galvanized steel wire.† This cable was manufactured by the Simplex Wire and Cable Company, of Boston. The cable was delivered by motor truck to the Navy Yard, Boston, in four reels. The Coast Guard Cutter "Pequot" was detailed to lay the new cable in Ambrose Channel and was at the Navy Yard, Boston, to receive this cable. Upon arrival of the four reels at the Navy Yard, representatives of the cable company made necessary cable splices so that it was stowed on board the "Pequot" in one continuous length. This procedure was of great help, as it eliminated the extra work and delay which would have been encountered should splices have been made during cable-laying operations.

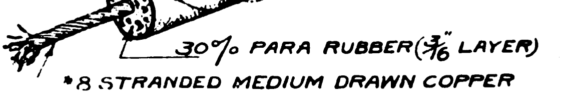
*12 GALVANIZED STEEL WIRE
JUTE
TAPE
30% PARA RUBBER(3/16" LAYER)
*8 STRANDED MEDIUM DRAWN COPPER

FIGURE 3

While the cable was being put on board the "Pequot," a special connection was made to the end of the cable. Figure 4 shows sketch of this connection. The connection made between the internal conductor and the armor was for the purpose of eliminating the grounding plate and the attendant mechanical and electrical difficulties encountered when using this plate. It was figured theoretically that the low resistance offered by the large surface of the grounding plate (4 sq. ft. or 0.37 sq. m.) to the return current thru salt water between the plate and the armor was approximately equal to resistance of the short length of the internal conductor (6 inches or 15 cm.) as shown in Figure 4. The brass cap covering the rubber insulation at the end of wire was used to keep the salt water from seeping back into the cable between the rubber insulation and the wire.

---

* Diameter of number 16 wire = 0.05 in. = 0.127 cm.
† Diameter of number 12 wire = 0.08 in. = 0.203 cm.

The "Pequot" arrived at New York, July 31, 1920. Three days were spent in under-running the Western Union, Army, and Police cables which cross the Narrows between Forts Hamilton and Wadsworth, after which operation the "Piloting" cable was placed under these cables. This was accomplished by hoisting up cables one by one and passing a 60-foot (18.3 m.) sailing launch with 2,000 feet (600 m.) of cable on board under the

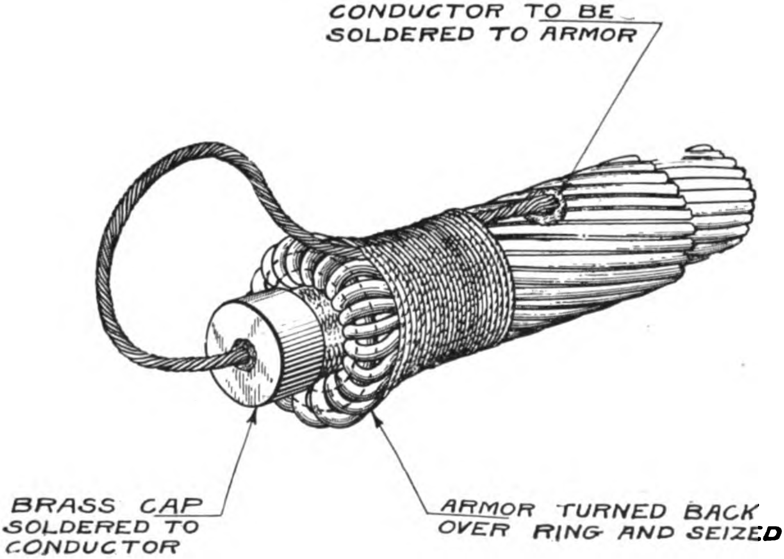
CONDUCTOR TO BE SOLDERED TO ARMOR
BRASS CAP SOLDERED TO CONDUCTOR
ARMOR TURNED BACK OVER RING AND SEIZED

FIGURE 4

cables and then allowing the cables to be released and sink to the bottom. After this operation, the sailing launch carried the remainder of the cable ashore and placed 500 feet (150 m.) of cable on the dock at Fort La Fayette.

When the shore end of the cable was secure, the "Pequot" headed for the middle of the channel and on reaching this point on the course, a cable clamp (see Figure 5) was placed on the cable, and by means of shackles and 0.31 inch (0.8 cm.) chains an anchor was made fast to the cable and lowered over the side. From this point the "Pequot" followed as close to the middle of the channel as was possible on her way out of the Ambrose Channel, passing to the left of the entrance buoy and completing the work of laying the cable when at a point 1,900 yards (1,740 m.) from the Ambrose Light Vessel. The cable was anchored at the two turns and also at the end, as shown in Figure 6. This cable was approximately 16 miles (26 km.) in length and laid in a period of six hours. Upon completion of the cable laying, August 6, 1920, test was made to ascertain whether the cable was in good condition, the result of which test showed that it was possible to obtain a current flow of 3.5 amperes when using 400 volts supplied by a 1-kilowatt 500-cycle generator at Fort La Fayette. Upon noting that the cable was apparently in good condition a power unit was installed at Fort La Fayette for this cable. This unit shown in the schematic diagram Figure 7, consisted of a 2-horse-power two-phase 220-volt 60-cycle induction motor (the current for which was supplied from a commercial source), which was connected by belt

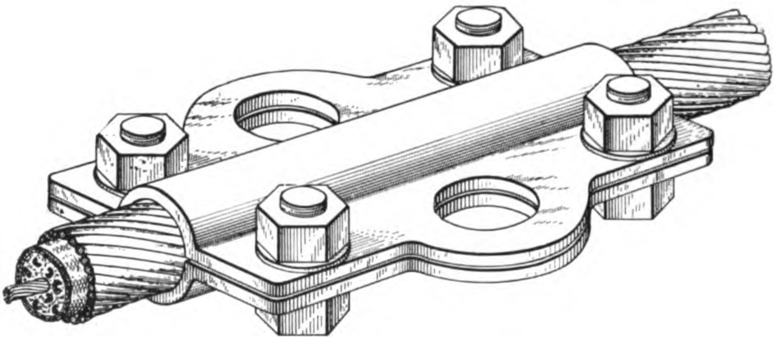

FIGURE 5

drive to a 1-kilowatt Navy Standard, 500-cycle, 120-volt motor generator. The generator voltage was stepped up to 400 volts

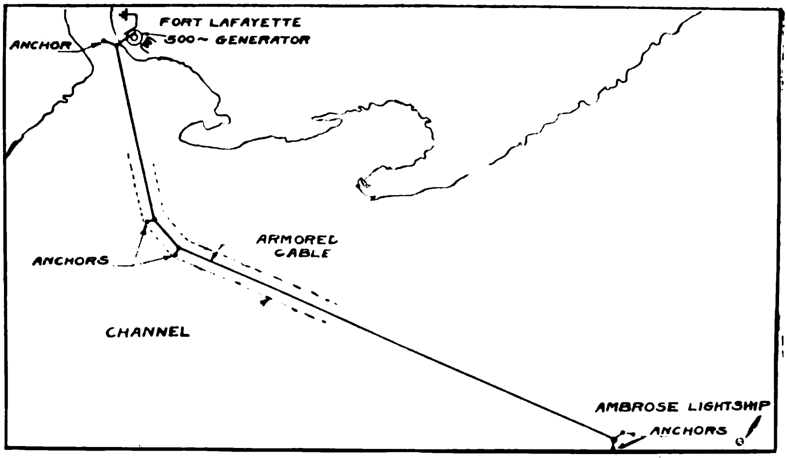

FIGURE 6

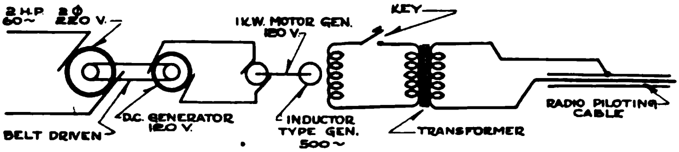

FIGURE 7

by means of a transformer and the output of the transformer supplied direct to the cable. An "Omnigraph" transmitter connected to a Navy Standard relay key was used to send distinguishing signals into the cable. After improving the receiving equipment it was found that the step-up transformer could be dispensed with, thereby simplifying to a certain extent the power unit. A schematic diagram of the simplified circuit is shown in Figure 8.

The cable before being laid was found to have an impedance of 50.2 ohms at 500 cycles and a direct current resistance of 50 ohms. The capacity of the cable measured at 800 cycles was 5.7 microfarad. After laying the cable, it was found that the impedance of the cable circuit was 123 ohms at 500 cycles, and that there was a lagging power factor, which when measured was found to be 0.80. The inductance (calculated) of the cable was 38.28 millihenrys.

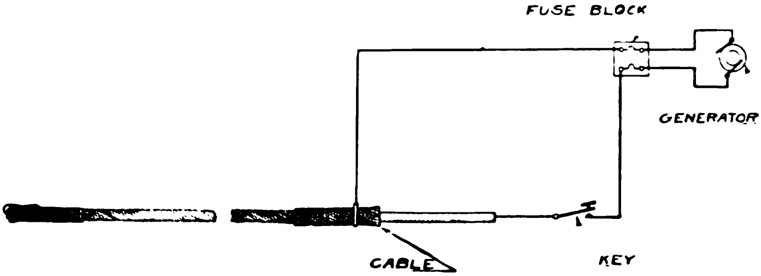

FIGURE 8

Having completed the installation of the power unit, work was started on the receiving apparatus. Three types of coils were constructed, one having 400 turns, one 600 turns, and the other 800 turns, wound on a wooden frame four foot (1.2 m.) square. These coils with the exception of the 400 turn coil, were wound with number 20 Browne and Sharpe gauge double cotton covered copper wire.* The 400 turn coil was wound with number 24 wire† which size wire gave considerable trouble, as it stretched easily. It was, therefore, practically impossible to wind two coils with this wire and have them of the same resistance. It was imperative that both coils have the same resistance and therefore resort was made to re-winding the 400 turn coil with number 20 wire which gave very satisfactory results. The coils were layer-wound, and impregnated with beeswax and boiled linseed oil.

The resistance of the coils are as follows:

Coil	*Resistance*
400 turn	64.3 ohms
600 turn	100.2 ohms
800 turn	130.9 ohms

Leads from each coil terminated in a watertight junction box on the coil frame, from which portable leads (lead and armored duplex cable) were led to a double pole double throw switch and from there to a type SE-1,600 two-step audio frequency amplifier and the Navy telephone receivers.

---

* Diameter of number 20 wire = 0.032 in. = 0.082 cm.
† Diameter of number 24 wire = 0.02 in. = 0.051 cm.

The double pole double throw switch had to be re-designed so that it would at no time completely open the input circuit of the amplifier, as under such a condition the amplifier would howl and deafen the observer. A rotating switch was therefore designed which when rotated made contact with one coil before disconnecting the other coil.

Upon completing work on the receiving equipment, the U. S. S. "Algorma," a large Naval sea going tug, was fitted out with the receiving equipment. The amplifier and switching device was installed in the pilot house and the collector coils were rigged out from the opposite sides of the vessel on a level with the upper deck and approximately amidships. In this condition the coils were about fifteen feet (4.5 m.) above the waterline. The coils were rigged on separate outriggers by use of which the coils could be swung clear of the ship's side in a vertical position to a maximum distance of six feet (1.8 m.).

When all circuits (transmitting and receiving) were found to be in perfect condition the "Algorma" steamed out the Ambrose Channel and conducted preliminary experiments on the system. During these experiments it was found that the steel hull of the "Algorma" had a very pronounced shielding effect on the respective coils, which was not noted during the New London experiments. This shielding was such that it was possible to note easily when approaching the cable the exact location of the cable with respect to the vessel. When the vessel was directly over the cable a signal of the same audibility was received on each collector coil, while if the vessel moved to the right or left of the cable the coil nearest to the cable picked up the strongest signal, while the coil furtherest away from the cable picked up a signal of markedly less intensity.

Figure 9 gives an idea of the relative audibilities received by the nearest coil when vessel is at different distances from the cable. It can be seen from this graph that the shielding of the hull of the vessel is responsible for the big decrease in audibility when vessel is directly over cable, and the tremendous increase in audibility when the vessel is approximately 30 feet (9.2 m.) either side of the cable. Further explanation of this point may be given by reference to Figures 10 and 11, which shows apparent effect of the electromagnetic field on the respective collector coils.

This pronounced shielding effect was found to be very helpful since by its use a vessel could keep the maximum signal in the port coil and steer a course which would always keep the vessel on the correct side of the channel.

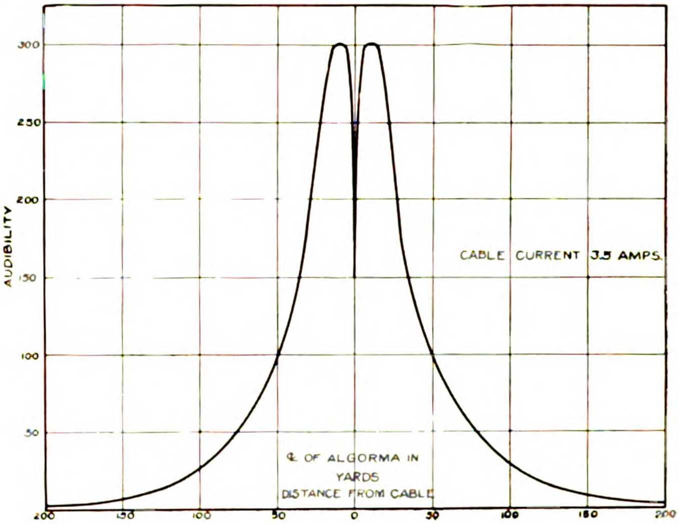

FIGURE 9

After noting the shielding effect, experiments were conducted to ascertain the correct distance that the coils should be from the side of the vessel, the results of these experiments show that the coils should not, for a vessel of the "Algorma" type, be at a greater distance than three feet (0.9 m.) from the side of the

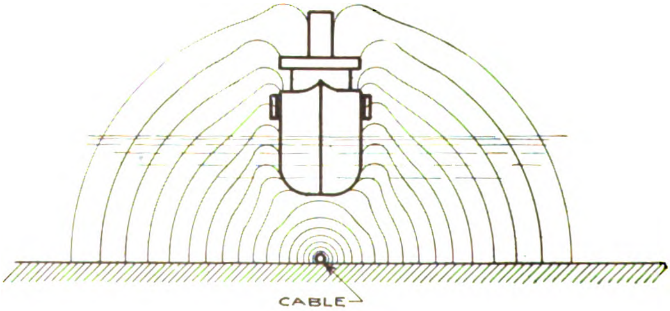

FIGURE 10

vessel. Should this distance be exceeded, the shielding effect of the hull would be annulled to a great extent. It was also discovered that tilting the coil at different angles to the vertical plane was beneficial with reference to increased signal strength.

Before completing the day's work, and on the return trip, the "Algorma" tried various experiments in picking up signals from the cable, chief among which was to approach the cable at right angles to note how far away a vessel could be and still pick up signals from the cable. It was found that the cable could be picked up at a distance of one hundred yards (90 m.), and, by noting the gradual increase in signal strength, the navigator could easily note that he was approaching the cable on a course at right angle to the cable.

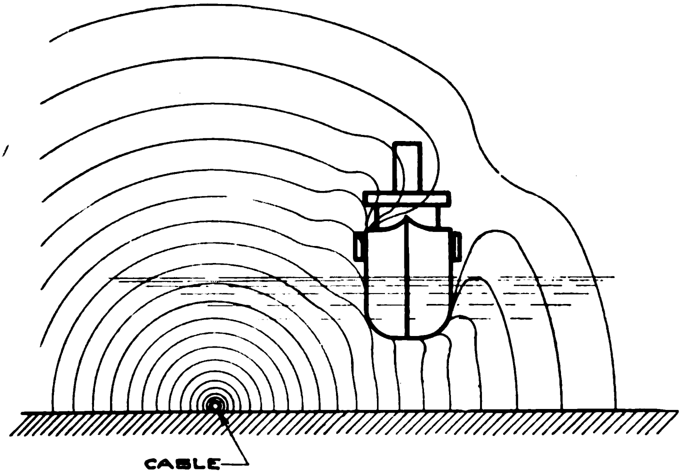

FIGURE 11

Having determined certain major navigational features of the cable on the first trip, the "Algorma" made a second trip on the following day. During the return trip to the city, the pilot house of the "Algorma" was blanked off by means of shutters so that the navigating officer could not see daylight, and by means of the receiving apparatus of the system he was able to bring the "Algorma" thru the Ambrose Channel without receiving aid from any other source. At no time was the "Algorma" more than 50 yards (46 m.) from the cable, except at the 30° turn where the officer deviated 100 yards (92 m.) off his course before settling on the new course. When consideration is given to the fact that the navigating officer of the "Algorma" was a perfect stranger to the system, having only three hours' preliminary instruction, it is to be granted that this new aid to navigation has great possibilities.

During the succeeding tests on board the "Algorma," much information was obtained, chief among which may be given as follows:

A current flow of three amperes into cable is sufficient for all needs in water up to a depth of 200 feet (61 m.).

A collector coil having 800 turns of wire gave twice the audibility as the 400-turn coil, which was to be expected.

It is important that the coils shall have identical electrical constants or else the system will not function properly.

The use of tuned resonant receiving circuits increased the efficiency of system 1,000 percent., under which condition the cable can be picked up at 1,000 yards (920 m.) on either side of the cable, which further increases the possibilities of the system for deep water work.

When using a single tilting coil for determining the location of the cable, the shielding effect of the steel hull of ship blurs both the maximum and minimum signal received by the coil, thereby rendering this method inoperative. Figure 12 shows a graph of signal strength plotted against position of coil relative to a vertical plane when the vessel was 30 yards (28 m.) from cable.

Very little difference was noted in the received signal strength when the coil was submerged below the surface or placed above the surface of water. This gives very valuable information with reference to the future design of coils and their location.

The use of the loud speaker was found to be impractical for this system as the minute energy received at a distance from the cable will not actuate the diafram of a loud speaker, and only when the vessel was within forty yards (37 m.) of the cable was it operative.

The present cable has high resistance, and the use of a larger internal conductor is preferable for efficient operation. At present, the power used costs ten cents per hour, while by use of a larger internal conductor this will be reduced to five cents per hour. This result may be accomplished by an increase of 20 percent over the cost of present cable in the purchase of a new type cable. Should the old type cable be used for future installations, which require 20 miles (32 km.) or more of cable, a special 500 volt machine would have to be designed, while with the adaption of the larger cable the present Navy Standard motor generator units can be used.

The impedance of the return path thru salt water and earth is theoretically many thousand times less than the impedance of the return path thru the armor, and therefore, the major part of the current will return thru the water, thereby creating a resultant magnetic field. It is thought that the effect of the 500-cycle current thru the cable has a special concentrating effect on the return current path thru water, whereby it tends to bring this return path close to the cable. This assertion is based on the fact that no stray current return paths were noted, which would have been the case if direct current had been used to energize the cable.

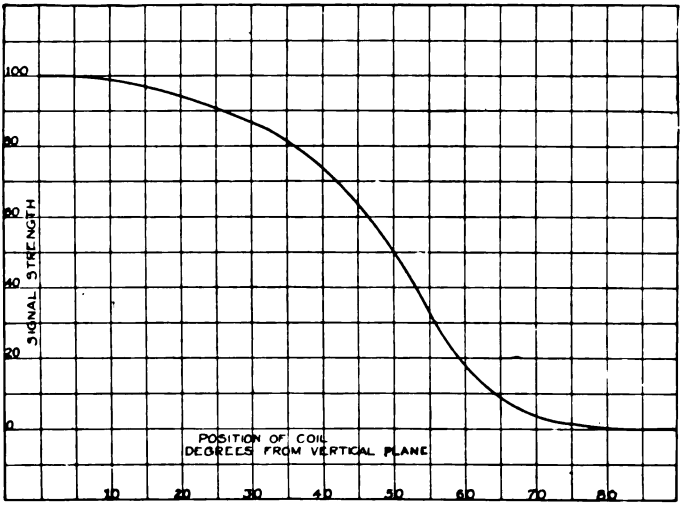

Figure 12

The present connection at the end of the cable between internal conductor and the armor is apparently satisfactory, but it is believed that the resistance of the return path thru earth, water, and armor may be greatly reduced by using a special type of grounding box, a tentative design of which is shown in Figure 13. This box will offer more surface to water and earth, thereby reducing resistance at that part of the circuit, and also it will protect the exposed internal conductor from corrosion.

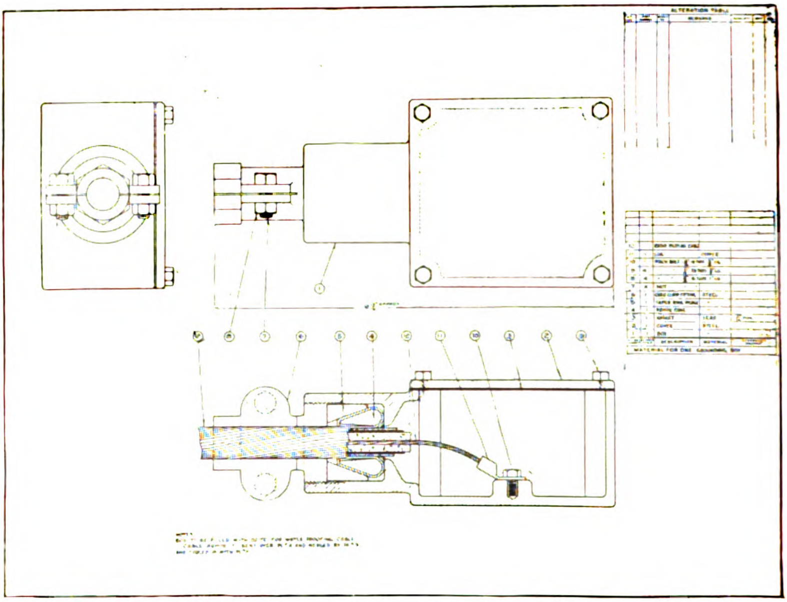

FIGURE 13

THE NEW YORK DEMONSTRATIONS

When the greater part of the preliminary experimental work was completed at New York, arrangements were made whereby the destroyer "Semmes" was assigned for duty in connection with the public demonstration of this system. The object of this demonstration was to bring to the attention of the commercial world the possibilities of this system as an important aid to navigation, especially for the navigation of harbors during foggy or stormy weather.

On October 6th to 9th, inclusive, 1920, demonstrations were given to representatives of various radio companies, shipping interests, pilots' associations, governmental bureaus, naval attachés and others interested in this system. During these demonstrations the various representatives were given an opportunity to inspect the apparatus and personally to pilot the vessel by means of this system.

On each day of the demonstration, during the return trip to the city, a representative of either the Pilots' Association or a steamship company volunteered to pilot the "Semmes" thru Ambrose Channel. In order that the person volunteering for this duty could better demonstrate the workings of this system, the bridge was blanked with strips of canvas so that it was impossible for the person to note in which direction the ship was being steered. Four persons volunteered for this work, all being able to follow the cable, and at no time were they more than one hundred yards (92 m.) from the cable. On Saturday, October 9, 1920, Captain Battle, of the Cunard Liner "Virgilia," volunteered to pilot the "Semmes" back to port, and gave an excellent demonstration of the possibilities of the system. Captain Battle was a total stranger to the system, but after a little coaching piloted the "Semmes" with such accuracy that he kept the vessel at a distance of 50 yards (46 m.) from the cable, and on the correct side of the channel. This was accomplished by striving to keep the "Semmes" in such a position as to obtain a certain signal strength from the port coil, which operation was entirely practicable.

Captain's Battle's work shows the feasibility of the use of one cable, altho certain persons present, who were technical men, thought that two cables would be better, one cable to be energized with 500-cycle current, and the other with 1,000-cycle current, one cable to be used for outgoing traffic and the other for incoming traffic. One hundred and fifty persons were present at these demonstrations, and approximately ninety percent. were in favor of the single cable. All present were convinced of the practical possibilities of the Audio Piloting Cable, and had nothing but praise for the system.

Among the persons present, interested in the system, from a technical standpoint, were Messrs. E. F. W. Alexanderson, H. Buckley, G. H. Clark, H. L. Curtiss, F. Lowenstein, and G. H. Lewis. The writer had many interesting discussions on the technical and practical details of the system, with the above-mentioned persons, from which much valuable data was obtained.

Special effort was made by the writer to obtain the ideas of numerous seafaring men, on the practical possibilities of the system. The majority of the persons interviewed said that the cable should be laid beyond the light vessel, to a distance of at least five miles, at which place vessels could make good use of the cable, and thereby pick up the light vessel, the sight of which would serve the psychological purpose of giving the navigator more faith in the system and also a point to set a new course from.

The proposed method to be followed, in using the cable, is to pick up the cable at sea and follow it to the light vessel, from which point, by means of a stop watch, speed chart, and the cable, it will be possible when making standard speeds to know when the ship is approaching the turns in the channel, and thus be doubly assured of safely navigating the ship into the anchorage near the Narrows.

FUTURE WORK

The problem presented to date has been apparently met with the aural receiving equipment, but there is a demand for some kind of a visual device which will indicate directly the location of the cable. Work is now being undertaken by the New York Navy Yard to design such a device.

There are many improvements to be made in the design and installation of the coils, amplifiers, condensers, and switching devices which comprise the aural receiving equipment. Work on this equipment is being done by the New York Navy Yard, in order that Naval vessels can be supplied with this equipment.

It is proposed to build a power unit similar to Figure 14, which will eliminate the use of the "Omnigraph" transmitter and the relay. This unit will consist of a 4-horse-power 220-volt 2 or 3-phase induction motor, a 2-kilowatt 250-volt 500-cycle generator, an exciter for supplying direct current for generator fields, and a commutator for sending characteristic

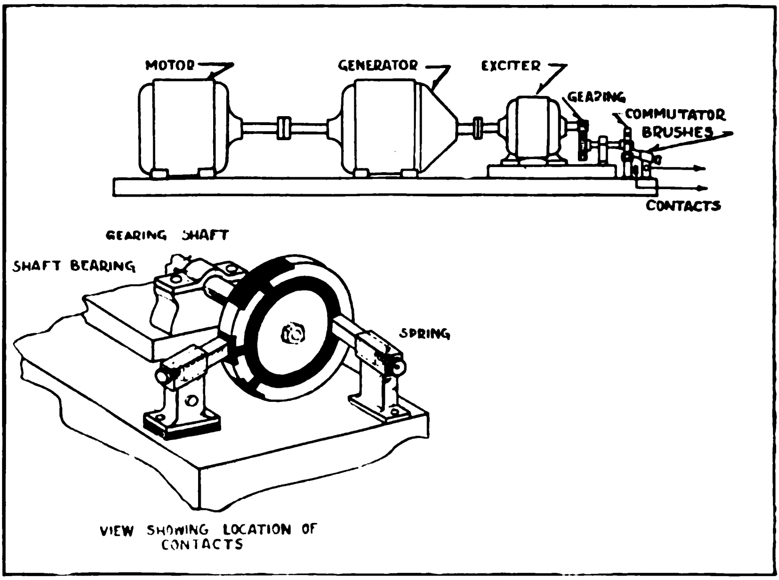

FIGURE 14

signals into the cable. The generator or exciter field rheostats can be used in place of a series regulating device in the cable circuit, by the use of which rheostats the current flow into the cable can be efficiently varied within desired limits.

The cable for the New York Harbor will most likely be laid to a point at least one mile (1.6 km.) beyond the light vessel, from which point it will divide and be laid in a north-easterly and southerly direction, for a distance of approximately five miles (8 km.) Such a combination of cables could take care of transatlantic and northern bound traffic. The northeasterly cable could be an additional safeguard to keep vessels from running aground on Long Island.

It is understood, upon completion of the New York experiments, that the Bureau of Lighthouses, Department of Commerce, will take over the work of installing and maintaining cables in the important harbors of this country.

Arrangements are also being made at the International Communication Conference, now in session at Washington, whereby this aid to navigation will be internationalized and adopted by all countries having seaports.

CONCLUSIONS

The aural system in its present state is a success from a navigational standpoint. Seafaring men are entirely in favor of immediately applying the system for navigating vessels thru harbors, during inclement weather.

The installation of cable in harbors costs comparatively little in comparison with other navigational aids. Thus, the total cost of the proposed New York Harbor installation will not exceed $50,000, which is about equal to the cost of certain individual beacons and buoys now used in and about the New York Harbor.

When vessels of the Cunard, White Star, and other steamship lines are detained outside of the harbors, because of inclement weather, the hourly maintenance cost per vessel is from $500 to $4,000. Figuring the cost of receiving equipment for the Audio Piloting Cable system at approximately $1,000 per vessel, it can be seen that the equipment will pay for itself within a period of a few hours. It is also thought that the insurance companies will give lower rates to vessels fitted out with this equipment, which will be an additional benefit to the ship owner.

The advantages of the system are numerous and open the way to greater safety at sea, especially when this system is used in connection with the present chain of United States Naval Radio Compass Stations. Vessels, when approaching the coast, can obtain radio compass bearings and from these bearings steer a course for the mouth of the harbor, at which place they will pick up the cable and follow a course over the cable to the anchorage inside of the harbor.

There are numerous other applications of the induction principle which will further simplify navigation, but as it is not intended to cover these in this paper, no description of them will be given.

In concluding, the writer desires to mention the names of the following persons who were responsible for the successful conclusion of the experimental work on this new system: Commander S. C. Hooper, U. S. N.; Commander R. F. McConnell, U. S. N.; Lieutenant-Commander E. H. Loftin, U. S. N.; Lieutenant H. W. Kitchin, U. S. N.; Ensign R. G. Sidnell, U. S. N. R. F., and Expert Radio Aid Harrison J. Lang.

SUMMARY: A summary of the historical development of audio frequency induction methods of piloting ships carrying coil receivers along current-carrying cables making the desired course is given.

A number of experiments carried out at New London and in New York Harbor are described in detail. The design and mode of use of the cable and the receiving apparatus are fully discussed; and the practical applications of the various systems of audio frequency piloting are given.

DISCUSSION

Greenleaf W. Pickard (by letter): In reading Mr. Crossley's interesting paper I am impressed by the striking audibility curve of Figure 9, with its approach to a null point when the steel vessel carrying the pick-up coils is directly over the cable. As the author points out, this sharp change in sound is very helpful, and I an wondering how this desirable feature could be retained, in the event that our Shipping Board's non-magnetic cement ships ever became popular.

Despite the near-century of history given by Mr. Crossley, I cannot help feeling that the art of induction piloting is yet in its infancy. We are all familiar with the desirability of a sharp null point in radio direction finding, and it would seem possible to do the same thing for an induction system. For example, if instead of a single cable with earth return, a pair of parallel insulated cables are laid, spaced apart say twenty meters (60 feet), and joined at their far ends, then a single pick-up coil, mounted amidships in a vertical fore-and-aft plane, would be unaffected when the vessel was directly over the center of the cable system, but would begin to receive with the slightest deviation to either port or starboard of this line, and the reception curve in a vertical plane normal to the direction of the cables would resemble Figure 9, but with an absolute null point at the center. A further advantage of this arrangement would be that the cable system is now insulated, and the station ammeter and a ground detector would furnish instant information of any mishap to the cable.

Over a suitable network of submerged cables, traversed by currents of controlled intensity and phase relation, any imaginable magnetic field might be made to hover, so molded as to produce any desired effect upon a coil system carried by a vessel. Clearly, we are at the very inception of a new art.

I am inclined to question the statement that "the effect of the 500-cycle current thru the cable has a special concentrating effect upon the return current path thru water, whereby it tends to bring this return path close to the cable." If this were so, it would be equivalent to putting one conductor of the circuit in a tube constituting the return conductor, and this, since the time of André Marie Ampère (who, by the way, deserves inclusion in Mr. Crossley's general history), has been recognized as a combination without external magnetic field.

Robert H. Marriott (by letter): Located, as I am, across the United States from New York, the notice of the reading of Mr. Crossley's paper did not reach me until the day of the meeting. This accounts for a brief discussion by telegram which readers may desire to have explained in some detail.

It appears that we are at the point where we have the science without the art or the theory without the practice, or the demonstrations without the service. Service is what the public needs and what the engineer and scientist want to deliver.

Many things have been said and repeated in scientific dignified terms. A little variation, such as less dignity in expression, may help to bring out what is best.

To make this anticipated art what we believe it should and can be, will require perseverance, energy, and then more perseverance. We should profit by our experience in the development of radio to prevent lost motion, friction and proscrastination.

The "cable theory" family has grown up, the "demonstration" family has grown up, but the "service" children apparently have never survived beyond the "lusty yelling period." Expert diagnosticians would probably attribute the pre-natal or early demises to lack of vitality, malnutrition or unsuitable environment. Young physicians freshly equipped with a large quantity of second-hand information might offer more interesting theories.

It looks as if Congress would have to furnish nearly all the food by appropriations. Depending on steamship companies for any appreciable nourishment may result in arrested development, cripples or more deaths.

A policy which makes the success or failure dependent on only one factor, namely, sufficient appropriation by Congress, should result in success, while a policy depending on a number of factors such as several steamship companies' appropriations plus congressional appropriations may result in failure and loss of successive appropriations.

Since the United States is now a maritime nation and the efficiency of its merchant marine depends, in part, on how easily and quickly the vessels enter and leave the ports of the United States, it is quite proper for Congress to see to it that their entrances and exits are made easy.

Ample current in the cable would make it easy for the steamship companies to do their part. Sixty cycle power of sufficiently high voltage, from commercial mains, would reduce first cost and operating costs. Duplicate low resistance cables would increase reliability and serve for a wide range of developments and refinements for commercial and military purposes.

Dealing with the first thought,—short-sighted instrument manufacturers and others may be against making it simple and inexpensive for the steamships to receive the pilot signals, because the more complicated and expensive the receivers are, the more manufacturers or service companies could charge the steamship companies or Government in profits on single units or for maintenance.

However, experienced manufacturers and service companies know that handicapping an art in its infancy results in an unprofitable, uncertain demand or no demand, while a healthy established art is a certain market for improvements.

Steamship managements and steamships are complex and there are numerous managements and numerous ships. Installing anything new on the ships means that accounts must be shifted, orders must be shifted, habits must be shifted, prejudice must be shifted, and materials must be shifted. Those accounts, orders, habits, prejudices, and materials have inertia and there are lots of those inertias, and they are not all alike. Lots of inertia means that a big force must be applied to get service or that the new thing must be designed to cause minimum shift in accounts, orders, habits, prejudices, and materials. Plenty of current in the cable seems to be the key to the situation.

A big force such as a compelling law is probably not a possibility at this time. Therefore, the practical thing to do, seems to be to minimize the difficulties attached to installing, operating, and maintaining receivers on vessels. Simple receivers can be used if there is enough current in the cable.

Using weak audio frequencies in the cable means that amplifiers will be required on ship board. The first cost of amplifiers alone may cause some of the various human elements in a steamship management to hesitate, postpone, dicker, or cancel the project. Also various individuals connected with the management usually make private inquiries of radio operators, inspectors, engineers, and their amateur friends and relatives. From these various sources they can get stories to the effect that amplifiers howl, the bulbs burn out, the batteries run down, the transformer circuits break open, the apparatus must be kept dry, a great deal of skill is required to locate the coils and apparatus properly and to operate them, lighting circuits and sparking generators and electrolysis and striking metal of the ship's machinery and vibration make noises in the amplifier, two amplifiers will not work alike, and one amplifier will not work twice alike. Also they can get more or less contradictory stories to the effect that amplifiers are wonderful things which anybody can operate. One class of salesmen may try to sell amplifiers to the steamship companies, which he claims will give no trouble, while another class of salesmen may try to sell them a service on the basis that a service company is necessary to instal the entire receiving system properly, instruct the users, and maintain the system. Another class of salesmen may try to sell them a service which also includes operation by their radio operators. As a result, the steamship management may be more or less divided in opinion and have a general idea that an inexpensive system might not be in working order when needed and a more expensive service might run them ashore instead of in the channel. The net result would probably be for most of the steamship companies to wait for some other company to try it first. Such waiting means delay if not failure because fogs do not occur relatively often. For example, at a given port, fogs which could not be traversed may not exist more than a total of one hundred hours per year or a little over one per cent. of the time. This may mean that a given vessel would have only one chance in a hundred of having an opportunity to use its apparatus in that port. And if only a few vessels were equipped there might be a long time between convincing demonstrations or a general discouragement as to the "worthwhileness" of the device, while with hundreds of vessels equipped, the cable price should be quickly saved to the nation. Such valuable services would keep up an enthusiastic interest and service.

The equipment of numerous vessels seems to be necessary to render sufficient service to create a permanent practice and public service. It appears that the surest and most effective procedure for such a port as New York, is to install a cable supplied with sufficient current to be receivable on shipboard with a simple durable coil and a pair of telephone receivers and a duplicate auxiliary cable for use in case the first cable is damaged. In a port like New York the cable would probably be damaged by anchors until a large number of ships were equipped with receivers so they would have no excuse for anchoring. These simple receivers would be so inexpensive and durable as to remove hesitation on the part of the steamship companies.

As the development of this art is for the public service, the Government could also quite properly expedite the equipping and reduce the ratio of expense to service by such expedients as follows:

(a) Giving steamship companies the data for construction of receiving coils.

(b) Advising steamship companies where coils and telephones can be purchased.

(c) Loaning sets of coils and telephones to each steamship company.

(d) Loaning coils and telephones to the masters, mates, and pilots to be used between pilot ship and dock.

(e) By operating the cable at certain hours on heavy sailing days for practice.

(f) By notifying the vessels as to when these practice signals are to be sent and requesting reports on how they were received.

A year of such procedure could result in more than a majority of the United States vessels being equipped and a number of instances of saving in time and money.

This latter situation should make a law possible if necessary, which law would compel all United States vessels to be equipped.

The co-operating with the steamship companies in this respect and the removal of the need to anchor should automatically stop the fouling of the cable.

With the art once established, the steamship companies would want improvements such as visual indicators, automatic devices, and special services and apparatus from service companies and manufacturers. Military branches would have at their disposal means for developing useful devices and for the guiding of the government craft in war and peace times.

Five years from now, New York harbor can have forgotten it was ever without pilot cable service or it can be expecting such a service some day.

RAPID DETERMINATION OF DISTRIBUTED CAPACITY OF COILS*

By

Ralph R. Batcher

(Western Electric Company, New York)

The common method of measuring the distributed capacity of a coil is to determine by means of a standard condenser connected across its terminals the amounts of capacitance necessary to place it in resonance with a number of known wave lengths. By plotting a curve between the values of wave length squared and the shunted condenser capacitance, a straight line is produced which, if extended, cuts the base line (or the capacity axis) at a point corresponding to the distributed capacity of the coil.

By means of an alignment or nomographic chart, after the plan of the one reproduced herewith, the necessity of making a curve and much of the procedure in taking the measurements are eliminated.

Figure 1 represents a typical set up for such measurements. The condenser C is first adjusted to a value about two-thirds or three-fourths (depending upon limits of scale C_1 on chart) of its maximum value and the wavemeter is then adjusted until it is resonance with the circuit LC. This value of capacitance is called C_1. Then the wavemeter is adjusted to a wave length just one-half of the first value and C is then varied until it is in tune with the new wave length. Designate this last capacitance by C_2.

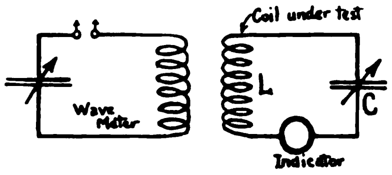

Figure 1

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* Received by the Editor, August 30, 1920.

Then, referring to the chart, a straight edge is so placed across the scales that it will cut the C_1 and C_2 scales at the values obtained during the test. Where this line crosses, the C_D scale will determine the distributed capacity.

The accompanying chart is made as follows: Three perpendicular lines are constructed, such as C_D, C_1, and C_2, so that the distance between C_D and C_1 is three times the distance between C_1 and C_2. The scales are laid off so that one unit of capacitance is equal to one unit of distance on the C_D scale, one-twelfth unit of distance on the C_1, scale, and four-ninths unit of distance on the C_2 scale. This arrangement of scales represents only one of a number of possible arrangements that will function in the same manner.

For more accurate results, the distributed capacity can be found starting with other wave lengths as a basis, and the resulting values averaged.

SUMMARY: A measuring method and chart for the rapid determination of the distributed capacity of a coil are given and explained.

MODULATION IN RADIO TELEPHONY*

By

R. A. Heising

(Western Electric Company, New York, N. Y.)

1. The radio telephone, as an improvement on the radio telegraph, depended upon the development of three things: (a) a source of sustained radio frequency currents, (b) a voice-operated means for controlling the amplitude of the radio frequency oscillations, and (c) an amplitude indicating detector. The first and third of these requirements were first met. Sustained wave generators of various forms and rectifying detectors were brought out about fifteen years ago, but a satisfactory modulator was not secured until later. The actual realization of the radio telephone was so dependent upon the modulator that the development of the latter may be considered the most important step in the production of the radio telephone.

The early experimenters in radio telephony made use of the ordinary telephone microphone as a modulator. Its inability to handle large powers, or to work in parallel was quickly observed. Building large microphones did not solve the problem and attention was diverted in other directions. To accomplish the desired results, many complicated mechanical and electrical contrivances were devised, but they did not prove satisfactory. Technically workable radio telephone systems comprising these crude modulators and sustained wave generators had been devised when there came into the field a new instrument which was destined to revolutionize completely the major part of the art.

2. The Audion

With the invention of the audion or 3-element thermionic amplifier by de Forest, the art of radio communication received its most valuable contribution since its conception. The audion has properties such that all three requirements for practical radio telephony were solved at once. Being essentially an amplifier, it can generate oscillations as can all amplifiers. It can modulate oscillations because it acts as a variable resistance in its amplifier action. It can detect oscillations because of the shape of its characteristic curve, and it can amplify weak signals to any degree of loudness. It is, because of its multitudinous uses, the most universal element in the radio field.

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*Received by the Editor, November 1, 1920. Presented before The Institute of Radio Engineers, New York, December 1, 1920.

As a modulator, the audion may be used for any type of generator: mechanical, arc, or audion generator, but the manner in which it is used varies somewhat in the different cases. The various forms in which it can be used in connection with the audion generator are considerably greater in number than the forms in which it can be used in connection with the others. In this paper there will be described only those forms which are efficiently applicable to medium and small power sets and in which the generator is of the audion class.

3. The Modulated Wave

Before going into the discussion of modulation systems, it may be desirable to say a word or two about the modulated wave. By a modulated wave or a modulated current is meant a sustained wave or radio frequency current the amplitude of which varies in accordance with the desired signal to be sent. An example is shown in Figure 1. The current is represented by the equation

$$i = A \sin \omega t \, (1 + K \sin \psi t) \tag{1}$$

where the average sustained amplitude is A when no signal is being sent. As soon as a signal wave, such as the simple sine wave indicated in the figure, is to be transmitted, the amplitude of the radio frequency wave varies accordingly as shown. It is indicated as varying between the limits of zero and $2A$ in the

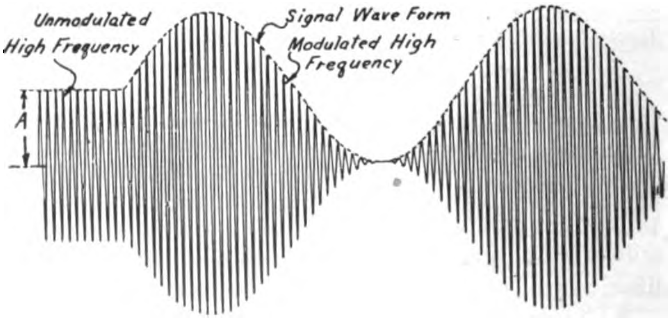

Figure 1—Completely Modulated Antenna Current ($K = 1$)

diagram. This wave is a completely modulated wave. Stated mathematically, we would say that in equation (1) the constant K is unity. In case the signal wave is of such an amplitude as not to reduce the radio frequency amplitude to zero at any time, we have an incompletely modulated wave as shown in Figure 2. In this case, K is less than unity. Such a condition is very undesirable. It wastes power. A received signal is dependent upon the variation in the transmitted wave amplitude rather than upon the antenna current reading. The wave in Figure 1 will give four times the received signal energy of that in Figure 2 altho the antenna currents will give approximately equal ammeter readings. As much power is required for the second signal as for the first, so that the efficiency of the second is only one-fourth that of the first. We should, therefore, always use radio systems which will give complete modulation.

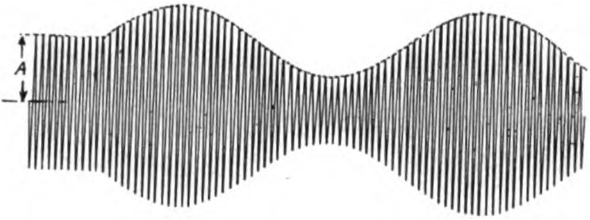

FIGURE 2—Modulated Antenna Current ($K = \frac{1}{2}$)

In actual telephonic conversations, the wave is never completely modulated at all times. A speech signal consists of several frequencies of different amplitudes. It is expected that the louder notes will completely modulate the wave while the weaker ones will not. This allows the possibility of the amplitude variation being reproduced at the receiving end. It is usually best so to construct the apparatus that the loudest notes will tend to overmodulate the wave. They are then distorted a small amount but the distortion is not objectionable. The increased volume of the weaker notes more than makes up for the distortion of the stronger ones, if the latter do nót consist of more than ten or twenty per cent of the signal.

A high frequency current such as expressed in equation 1 and shown in Figure 1 represents radio frequency power in the antenna which varies with time as shown in Figure 3. The expression for high frequency power

$$i^2R = RA^2 \sin^2 \omega t \, (1 + K \sin \psi t)^2 \tag{2}$$

when integrated over the radio frequency cycle gives

$$p = \frac{RA^2}{2} (1 + K \sin \psi t)^2$$

$$= \frac{RA^2}{2} \left(1 + 2K \sin \psi t + \frac{K^2}{2} - \frac{K^2}{2} \cos 2 \psi t\right) \tag{3}$$

This gives the power as consisting of $\frac{RA^2}{2}$ when not signalling ($K = 0$) and having single and double frequency components when a signal is sent. If K is unity, the effective radio frequency power rises to a peak value equal to 4 times the non-signalling value and has an average value of 3/2 the non-signalling value.

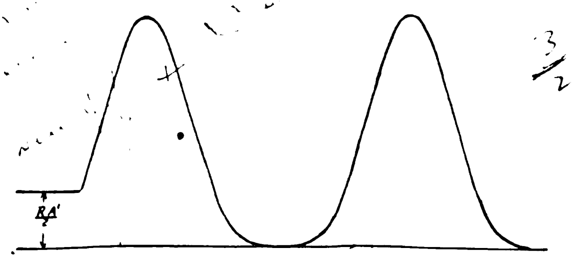

FIGURE 3—Effective Power of Radio Frequency Current in Antenna

Integrating (3) over a signal frequency cycle gives

$$P = \frac{3}{2} \frac{(A^2R)}{(2)} \tag{4}$$

as the radio frequency modulated power delivered to the antenna. That is, the power content of a completely modulated wave is 3/2 the power content of an unmodulated wave of the same average current. It is to be noted from this that, since the antenna ammeter reads effective value of current, the reading will rise by the factor $\sqrt{1.5}$ when a wave is modulated.

The modulated current in equation 1 can be resolved into a carrier wave and two side frequencies. The power contained in the components is:

Wave		Amplitude	Power	
Carrier	ω	A	$\frac{A^2R}{2}$	
Upper side frequency	$\omega+\psi$	$\frac{A}{2}$	$\frac{A^2R}{8}$	
Lower side frequency	$\omega-\psi$	$\frac{A}{2}$	$\frac{A^2R}{8}$	(5)

This indicates that $\frac{1}{3}$ of the radio frequency power is in the two side frequencies and $\frac{2}{3}$ in the carrier. In systems where the side frequencies only are transmitted and the carrier is not, but is put in at the receiving station, we will require only $\frac{1}{3}$ the radio frequency power to produce the same signal as can be produced by the side frequencies with the carrier frequency. This greater efficiency is often only apparent in tube sets, as many inefficiencies enter into the construction of such a system which neutralize much of the advantage to be gained. This type of radio signal is not, however, common, while the one indicated in the diagram and in equation 1 and containing the carrier is, and only such systems as produce the latter type of wave will be discussed.

4. Systems of Modulation

Systems of modulation may be classified in any number of ways. One classification divides them up into systems of:

1. Absorption.
2. Detuning control.
3. Amplification control.
4. Non-linear or assymetric conductance.
5. Generation control.
6. Frequency conversion.

This will fairly broadly cover the field. There are, however, many systems which do not fall exactly under any one of these classes but which may be combinations of two or more. The radio art is growing so rapidly that this classification may have to be extended at any time.

5. Van der Bijl System

One of the earliest radio systems we used is known as the van der Bijl system (United States Patent Number 1,350,752). It is the system which we employed in our experiments at Arlington in 1915 when we transmitted speech successfully from Arlington to Paris, San Francisco, and Honolulu. The system has been described briefly in the paper by Messrs. Craft and Colpitts in the "Proceedings of the American Institute of Electrical Engineers" of March, 1919. The circuit used at Arlington is shown in Figure 4. In Figure 5 is shown the modulator circuit together with a diagram which illustrates the principle of operation. This system is based upon the fact that the audion's characteristic curve is a parabola. It is classified under the head of modulation by amplification control.

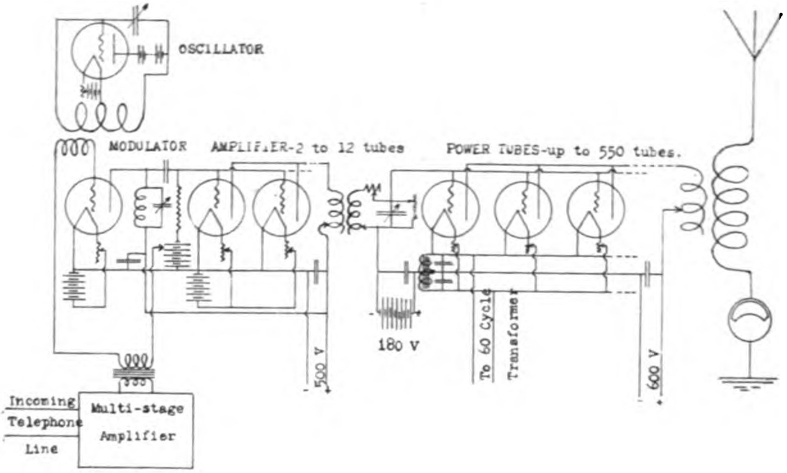

FIGURE 4—Experimental Circuit at Arlington, 1915

The equation of the tube as given by van der Bijl is

$$i = A(E_b + \mu E_c + K)^2 \tag{6}$$

The slope of the curve is given by the equation

$$\frac{d\,i}{d\,E_c} = 2A\mu\,(E_b + \mu E_c + K) \tag{7}$$

and is a straight line function of the potential on the grid. A characteristic curve and a curve indicating this variation in slope are shown in Figure 6. These equations hold only as long as E_b is positive, E_c is negative, and $E_b + \mu E_c + K$ is positive. In this system use is made only of that part of the curve for which these equations hold.

If a small radio frequency voltage is impressed upon the grid, the amplitude of the radio frequency current in the plate circuit

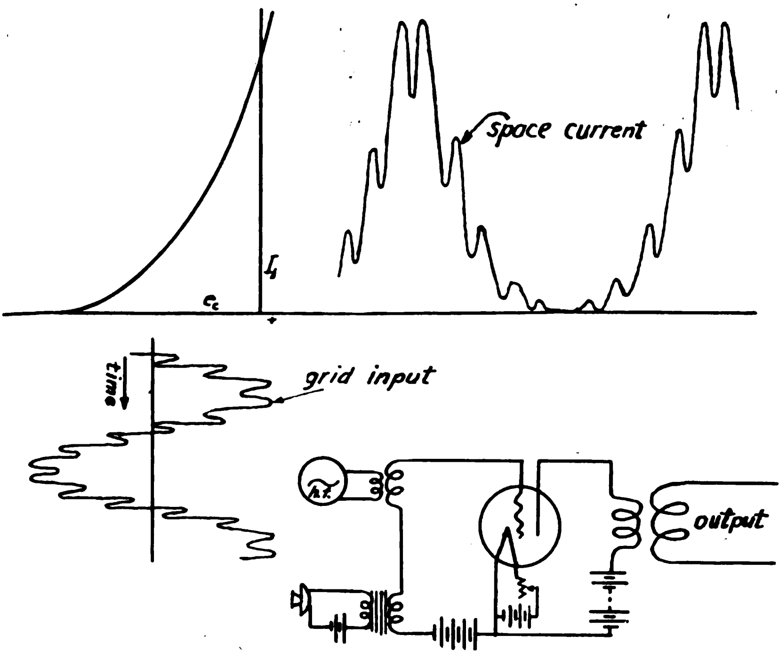

FIGURE 5—van der Bijl Modulation System

depends on what part of the characteristic curve the voltage happens to operate upon. If it operates where the slope is large the alternating plate current will also be large. If it operates near the bottom of the curve where the slope is small, there will be scarcely any alternating plate current. By sliding the small alternating voltage up and down the curve, a current with a continuously varying amplitude may be obtained, the magnitude of which is proportional to the curve slope at the point of operation. Thus by using the signal voltage to slide the small radio frequency voltage up and down the curve, it is possible to produce in the plate circuit an alternating current, the amplitude of which varies according to the signal voltage.

This is illustrated in Figure 5 by impressing upon the grid the voltage wave indicated with the time axis running downward. The amplitude of the radio frequency voltage is smaller than that of the signal voltage and the amplitudes of both are so chosen that only that part of the curve referred to before is operated upon. The resulting space current is then of the form indicated by the curve, the time axis of which runs to the right. Inspection will show that the amplitude of the radio frequency current is not the same at all times but that it varies in accordance with the signal. On taking out the radio frequency current by means of a tuned circuit it will be found that the envelope of the peaks of the wave is of the form of the desired signal, or in other words that the radio frequency current is modulated in accordance with the signal to be transmitted. The small amount of modulated radio frequency current secured is then amplified until of sufficient power to be put into the antenna.

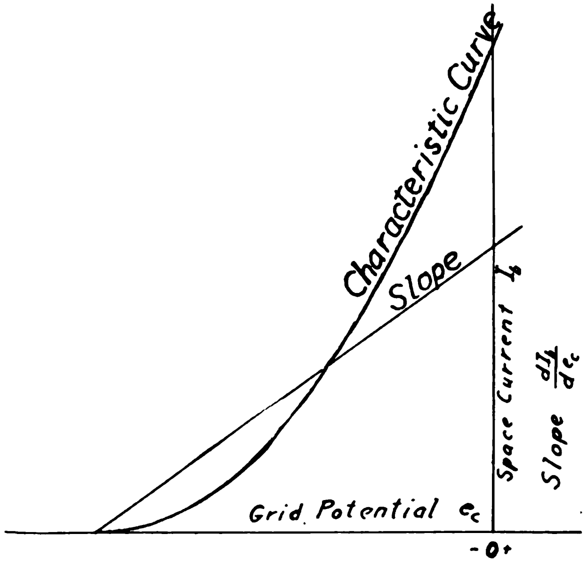

FIGURE 6—Characteristic Curve and Curve Slope of Audion

The efficiency of this system is determined by the last amplifier as is that of all systems in which a small amount of power is modulated and then amplified. By efficiency is meant plate efficiency only: modulated radio frequency power into the antenna circuit divided by plate power supplied. Filament power is not considered. The last stage of the amplifier takes most of the power and will be the only one considered in the simple discussion to follow. The power taken by the last stage is always $E_b I_b$ in a proper amplifier,[1] and the maximum power which it can deliver to the antenna is $\varepsilon E_b I_b$. ε is the maximum steady power plate circuit efficiency of the amplifier and runs from 25 to 90 percent, depending upon the type of amplifier.

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[1] See Appendix for a definition of a "proper amplifier."

The power delivered to the antenna is given by equation 3 as

$$p = \frac{RA^2}{2}(1 + K \sin \psi t)^2 \tag{8}$$

The maximum value that this has at any instant is (for $K = 1$) $2RA^2$ and this peak value must be supplied by the amplifier tubes. Therefore

$$2RA^2 = \varepsilon E_b I_b \text{ or } RA^2 = \frac{\varepsilon}{2} E_b I_b \tag{9}$$

Substituting in (8) and integrating over a cycle we get

$$p_{av} = \frac{3}{8} \varepsilon E_b I_b \tag{10}$$

or the efficiency of an amplifier delivering modulated current is only $\frac{3}{8}$ the plate circuit efficiency of the amplifier itself under maximum power conditions. The efficiency is lowered further if we consider the power consumed by the oscillator, modulator, and any previous amplifier stages.

The low efficiency of amplifier systems in comparison with some of those systems to be described later is caused by the requirement that full plate current be supplied even when no signal is being sent. Under this condition, the plate efficiency is about ¼ the maximum possible and a lowering of the system's over-all transmitting efficiency results. Sometimes it is suggested that this inefficiency be overcome by applying such a negative voltage to the tubes that the space current is reduced to a small amount under the non-signaling condition.[2] The over-all efficiency is thus raised almost to that of the other systems, but a big distortion occurs. Only half the modulated input wave then operates upon the grid and the alternating space current has an amplitude approaching the square of the input instead of a direct proportionality. This distortion is much greater than that produced by the curvature of the tube's characteristic curve and may be great enough to be objectionable. True amplification of the original small amount of modulated power is thus not secured. The choice between quality and efficiency in amplifier systems is a question to be decided according to requirements.

In the set used at Arlington in 1915, a small tube operating on a plate potential of 120 volts generated a sustained wave of constant amplitude. The incoming telephone line was provided with an amplifier in order that the signal impressed on the modulator would be of sufficient amplitude to carry the radio frequency sustained wave over the entire range of the modulator's characteristic curve. The modulated radio frequency current resulting was taken out by means of a tuned circuit and impressed upon two stages of amplifiers, the last one of which delivered power to the antenna. The first amplifier consisted of from 2 to 12 audions in parallel depending upon the wave length and the number of power tubes used. The power amplifier consisted of from 300 to 550 audions. Tuned circuits were used to take the radio frequency wave out of the first amplifier and impress it upon the grids of the power tubes. The amplifiers in this circuit differed in no way except size from those which would be constructed to amplify any single frequency. A few resistances were used in the various tuned circuits in the amplifier for the purpose of stablizing it against oscillations.

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[2] See Appendix for a definition of an "improper amplifier."

The filaments of the power tubes, and for a time of the first amplifier, were lighted by alternating current. In order to reduce the disturbing effect upon the modulated current by the alternating potential along the filament, a choke coil in which a middle tap was provided was connected across the leads. This tap was used as a common point for both the grid and plate circuits. This worked successfully and no disturbing effects due to the alternating filament potential were noticed at the receiving stations.

Photographs of some of these pieces of apparatus are given in Figures 7 to 10. Figure 7 shows the modulator and the amplifiers. The modulator tube with its circuit was in a box by itself. The amplifier tubes were partly in the box containing the circuits and partly in an additional box. All of these boxes were lined with sheet iron which was grounded, so as to reduce electrostatic disturbances and magnetic feed-back from the antenna or antenna circuit. The power tube racks are shown in Figures 8, 9, and 10. These racks were built to hold 50 audions each. Some of the audions were mounted and some were not. Some of the racks were installed and put into operation before a base had been designed for the tube.

It may be interesting to know that we had some bad quality trouble on account of the low resistance of the antenna. When working at 6,000 meters, the antenna inductance was about 1 millihenry and the total antenna circuit resistance was slightly under 2 ohms. These gave a sharpness to the antenna circuit tuning which reduced markedly the amplitude of the side frequencies. The sharpness was such that with loose coupling to the antenna, the quality was changed enough to make voices almost unrecognizable. It was therefore necessary to couple more closely than would be done to get the maximum power which could otherwise be secured.

The operation of the set as a whole was satisfactory. Completely modulated power was easily obtained and was of very good quality.

A slight modification of this radio system is given in Figure 11 (Patent Number 1,199,180). It consists of a modulator tube having 2 grids instead of one and having the oscillator supply

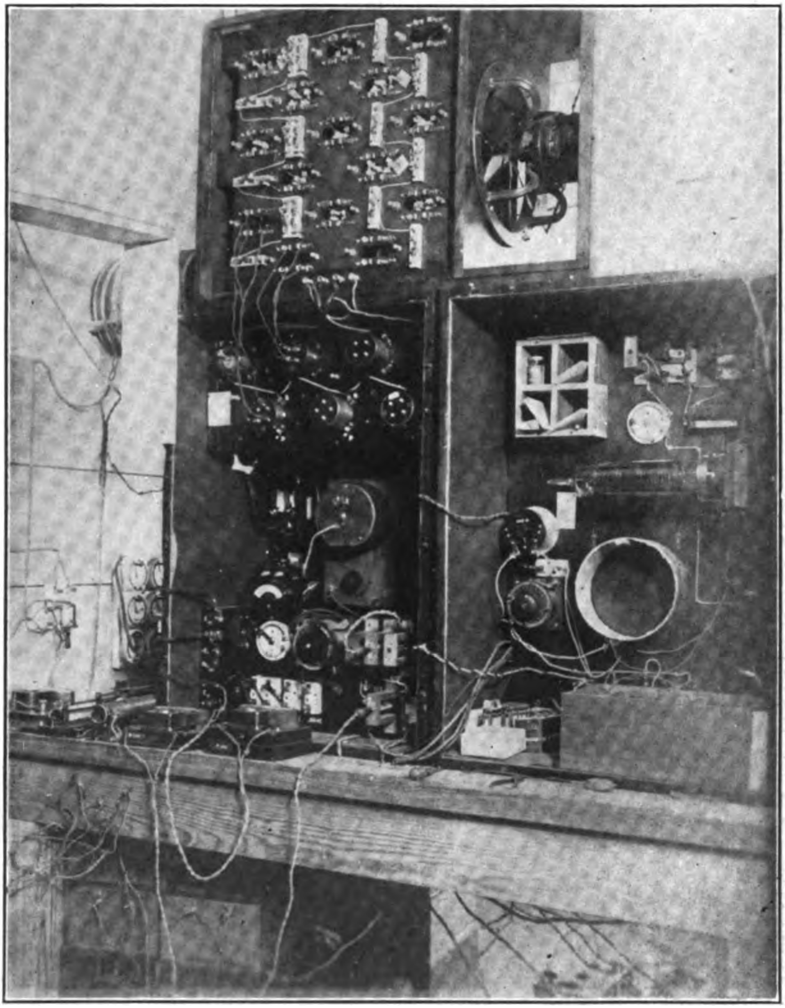

FIGURE 7—Modulator and First Amplifier in Arlington Experimental Set, 1915

a sustained wave to one grid while the signal frequency was impressed upon the other. The action of the two grids with their separate emf.'s is approximately the same as that of a single grid with the two emf.'s superimposed. Beyond the slightly different modulator construction, the system does not differ materially from that of van der Bijl.

6. Colpitts' System

Under the head of systems for the control of generation may be placed the radio transmission system devised by Dr.

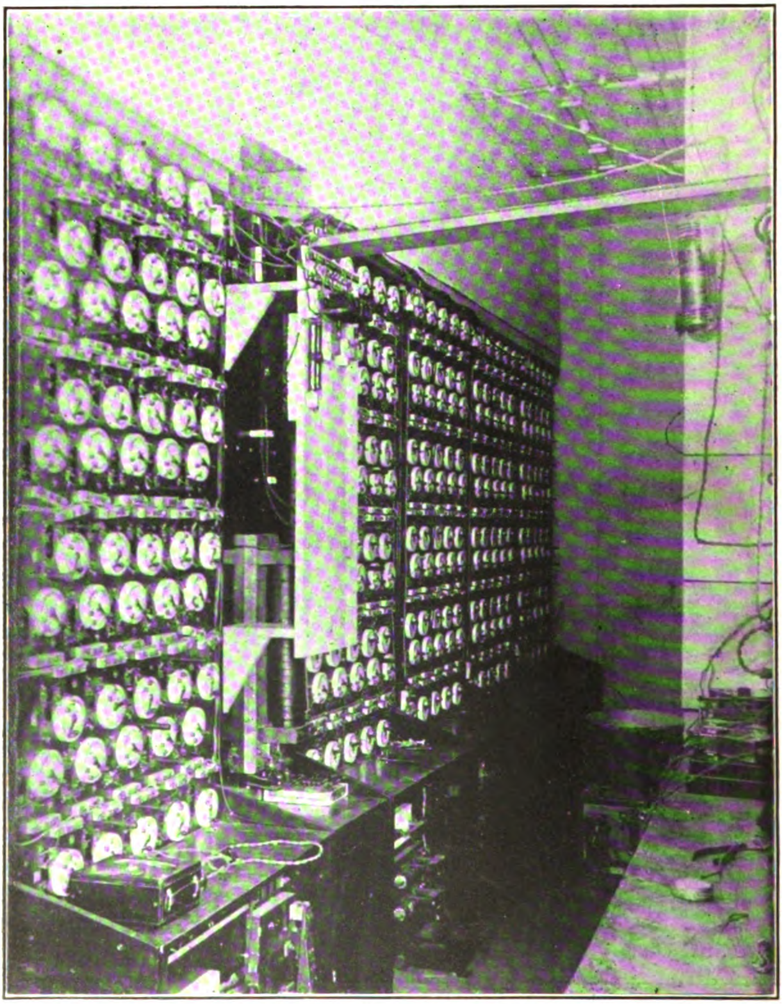

Figure 8—Power Tube Racks, First Group

E. H. Colpitts and shown in his Patent, Reissue number 14,380. The diagram is given in Figure 12. The principle in this case is that the grid of the tube, being a control member, can control the amplitude of the generated oscillations according to a signal impressed upon it. A modification, in which the circuit arrangement is different but which retains the principle, was made by Logwood (Patent number 1,218, 195) and is shown in Figure 13.

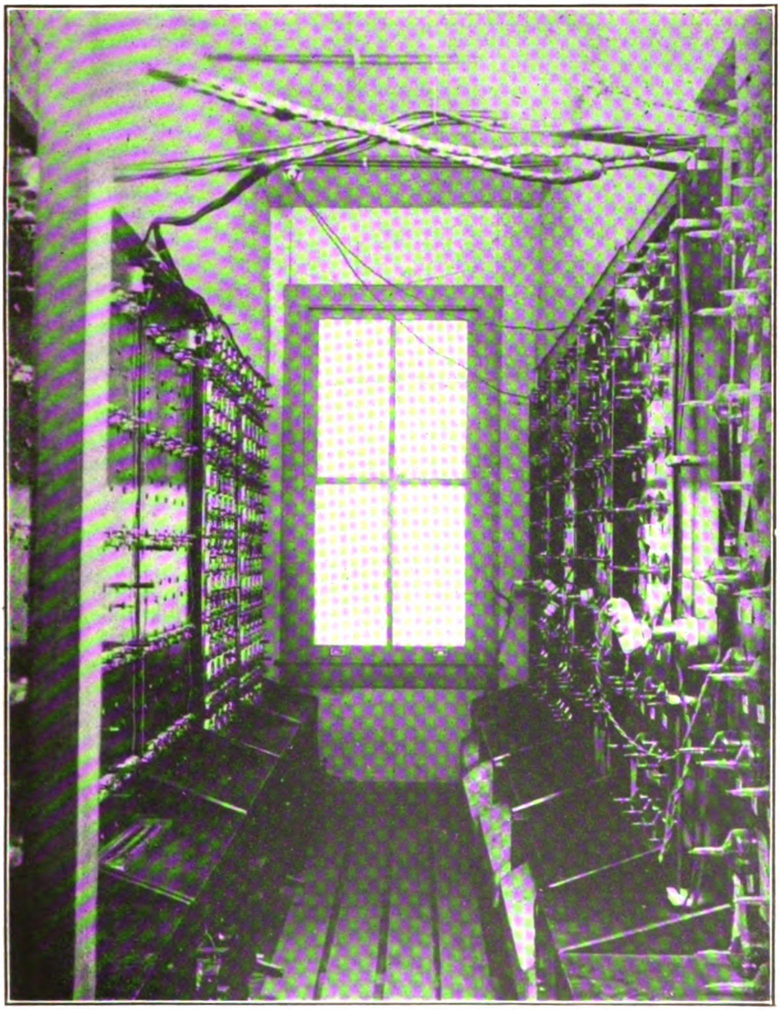

FIGURE 9—Power Tube Racks, Second Group

This type of radio system has not proved entirely satisfactory. Its greatest objection is that it does not readily give complete modulation. A control curve for a circuit of this type is shown in Figure 14. This curve gives antenna current as a function of the control potential applied to the grid. As long as the signal is small no trouble is encountered. If the signal potential works between the points *X* and *Y* on the curve, a modulated current such as curve *I* in Figure 15 is produced. If, however, the signal is a trifle stronger and goes to the left of *X*, a break

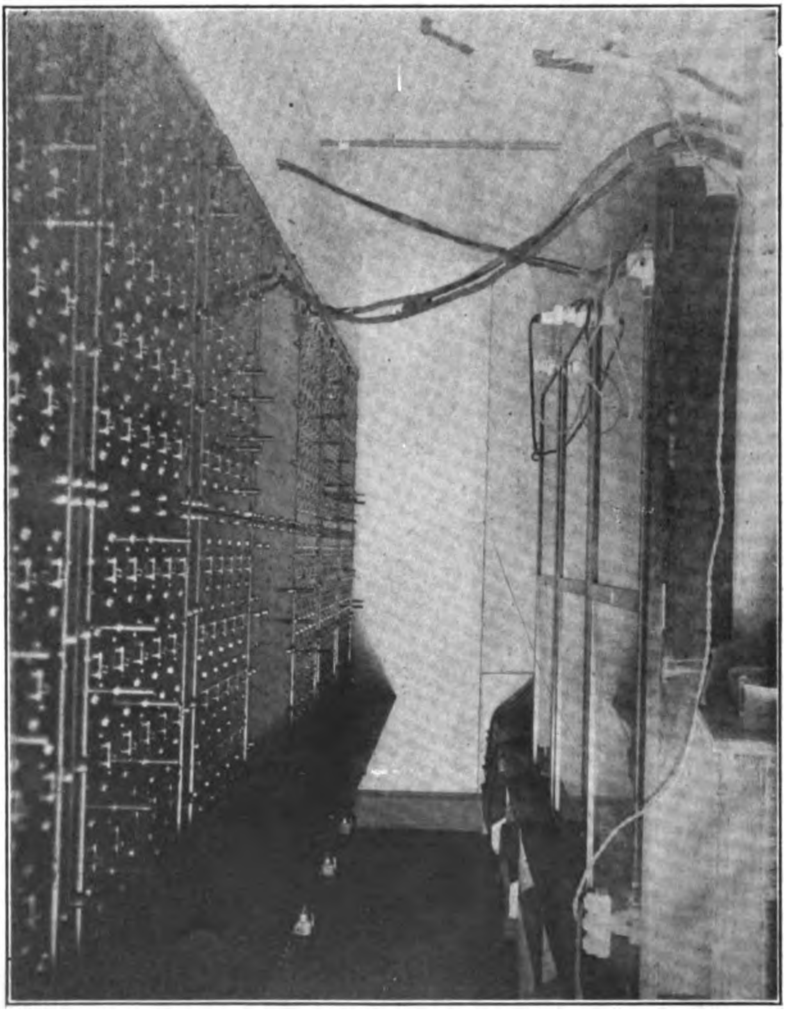

Figure 10—Power Tube Racks, Third Group

occurs. Oscillations cease abruptly at that point and do not begin again on the return movement until the point *B* is reached, when they start as suddenly. There is, therefore, a region between the dotted lines erected at *A* and *B* in which oscillations occur only so long as the controlling signal stays upon the upper control curve and does not pass to the left of the point *A*.

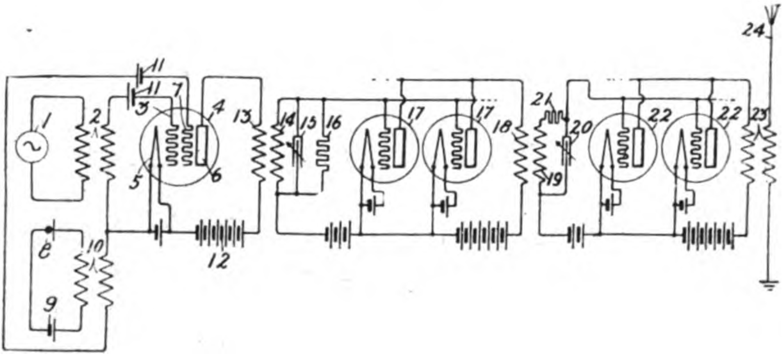

FIGURE 11—Double Grid Modulation System

Curve II in Figure 15 represents a wave produced by a signal which is too strong. It will be observed in this case that a sudden break occurs in the radio frequency amplitude at a certain point and that oscillations do not begin again until the signal potential has moved back to a different value than it had when the oscillations stopped.

This breaking up of the signal by a large amplitude in the signal

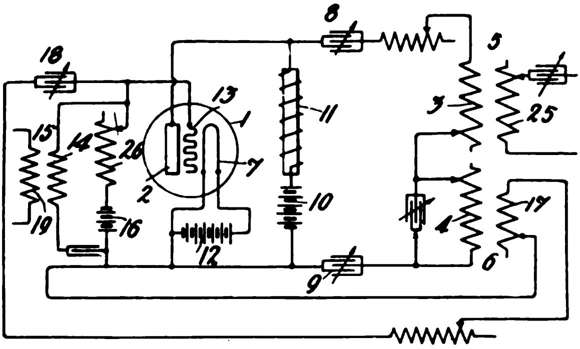

FIGURE 12—Colpitts' Radio System

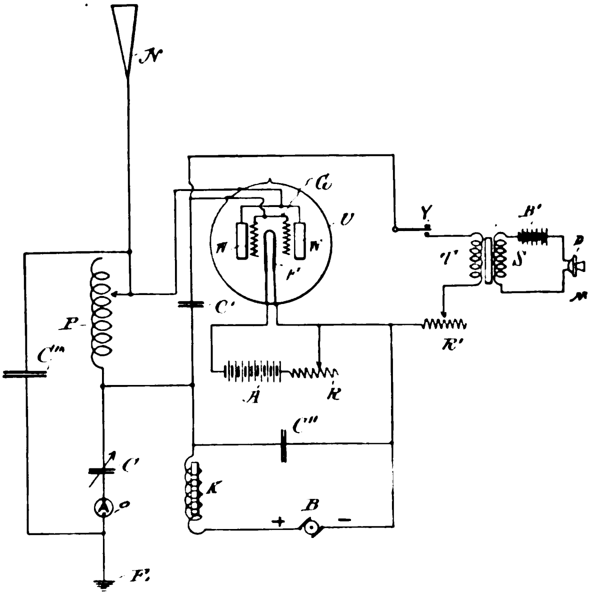

FIGURE 13—Logwood's System

waves, produces a very bad quality. If the signal is not large, the quality is good, but the modulation is incomplete and the system is very inefficient. If an oscillator is adjusted under ordinary conditions which give maximum power and very good efficiency, the percentage of modulation secured is of the order of 20 to 30 percent. It is possible to adjust oscillators so that

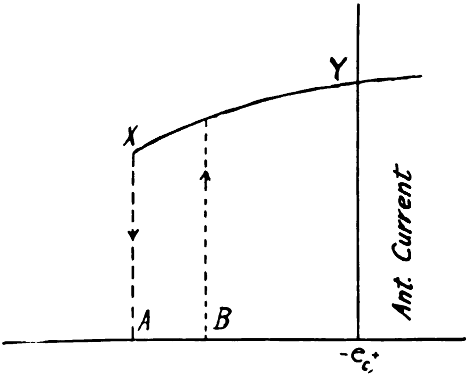

FIGURE 14—Controlled Oscillator Control Curve

the control curve is not discontinuous as indicated but of such a shape as to give complete modulation. However, such an adjustment is hard to secure and does not give good efficiency nor much power. A very careful adjustment must be remade each time the wave length is changed or each time the set is attached to a new antenna.

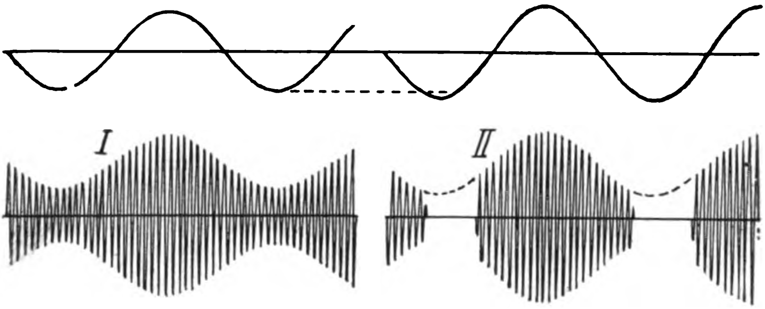

FIGURE 15—Effect of a Strong Signal on a Controlled Oscillator

A system operating on the control of generation principle appears at first as most nearly ideal. Such a system could be either the Colpitts' system just described or one of many systems where another tube is connected to the plate or grid to control the amplitude of the oscillations. In any case, it is necessary that the circuit be constructed to accomplish in its operation one of the following:

1. Vary the current taken by the oscillator, the voltage and efficiency remaining approximately constant.
2. Vary the voltage across the oscillator, the current and efficiency remaining approximately constant.
3. Vary the efficiency of the oscillator, the power supplied remaining approximately constant.
4. Vary both power and efficiency.

That is, the tube circuit must be so constructed that the power or efficiency is varied, or both.

Of these, the first two are ideal, but are not attained in practice. Most come under the third. The fourth cannot be discussed unless a large number of possible combinations are assumed, but the third can be quickly pointed out as inefficient in comparison to others.

The high frequency power in a simple modulated wave as given in equation 3 is

$$p=P\ (1+\sin \Psi\ t)^2 \qquad (11)$$

The largest value occurring at any instant is 4 P and the smallest zero. The oscillator must be capable of delivering 4 P power to the antenna circuit with the constant plate supply $E_b\ I_b$ and can do so at the efficiency ε which is the maximum plate circuit efficiency the oscillator can have. 4 P is therefore equal to $\varepsilon\ E_b\ I_b$

and
$$p=\frac{E_b\ I_b}{4}\ \varepsilon\ (1+\sin \psi\ t)^2 \qquad (12)$$

The efficiency must evidently be varied while talking according to the expression $(1+\sin \psi\ t)^2/4$ to give the proper modulated current. Integrating the equation for power over a cycle gives

$$p_{eff}=\frac{3}{8}\varepsilon\ E_b\ I_b \qquad (13)$$

This, it will be observed, is the same as for systems which modulate and then amplify as previously described (equation (10)), and is only half as efficient as some systems to be described later.

If the modulation is not accomplished by varying the efficiency, it might be accomplished by one of the first two classes, in which case the ideal condition is obtained. No audion radio circuit could be more efficient. However, the efficiency of oscillators varies with voltage and with current to a considerable extent and with the controlling circuit attached to the grid or plate, it is almost sure to vary. The result is that systems behaving ideally have not yet been produced. The best controlled oscillator circuits, tho equal in efficiency to those to be described later, have the disadvantages of complexity or distortion or both.

7. Modulation by Assymetric Conductance

A system which should be classed under the head of modulation by assymetric or non-linear conductance, is given in Figure 16. Radio frequency and signal frequency voltages are impressed upon a rectifier and a radio frequency tuned circuit in series. The radio frequency and signal frequency sources produce a wave as indicated in Figure 17. The signal in this case, as in all cases, is chosen as a simple sine wave of one frequency. The amplitudes of the signal wave and radio frequency wave are approximately equal tho not necessarily so. When this combination is impressed upon the rectifier, the unilateral conductance of the rectifier passes only the current flowing in one direc-

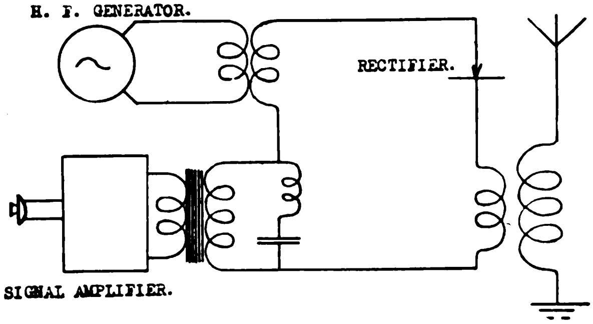

FIGURE 16—Assymetric Conducting Modulation Circuit

tion as shown in Figure 18. This rectifying action causes a modulated current to be produced. Inspection of Figure 18 will show that the current represented contains a modulated radio frequency component. The audio frequency component readily passes thru the radio frequency transformer in series with the rectifier while the radio frequency component transfers power to the antenna or tuned circuit. The radio frequency component contains numerous harmonics besides the modulated wave, which will cause the flattening of certain peaks. The tuned antenna or radio frequency circuit screen out most of these harmonics while conducting the modulated wave, and the flattened waves are corrected.

In the construction of a circuit of this type, it is necessary

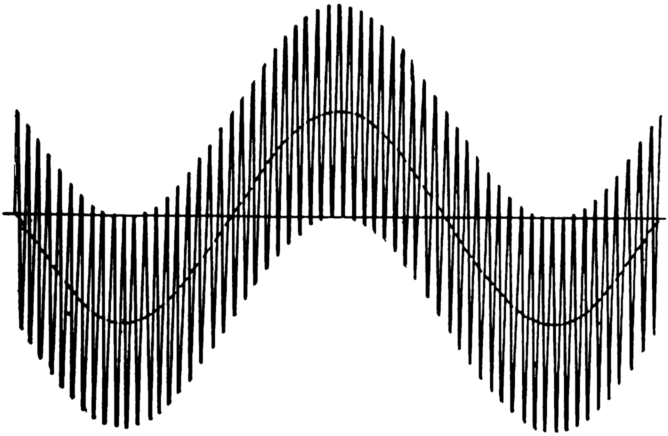

FIGURE 17—Input Wave to Assymetric Modulator

that the signal frequency amplifiers have low impedance for the radio frequency current and that the radio frequency generator have low impedance for the signal frequency currents. An air core transformer usually accomplishes the latter sufficiently, while, as shown in the diagram, a resonant circuit is placed across the signal frequency amplifier to accomplish the former.

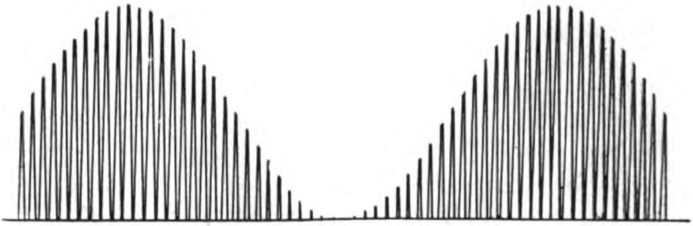

FIGURE 18—Rectified Current from Wave of Figure 17

The system as described considers the rectifier as strictly unilateral. That is not necessarily so. The conductance curve should be other than a straight line (preferably a parabola) in which case it will work satisfactorily. In a system as shown, the signal frequency source must supply practically the same amount of power as does the radio frequency source. This, of course, is not delivered to the antenna in any way and the efficiency of the system is between 25 and 50 percent. If only a small amount of power is modulated and then that is amplified into the antenna, the efficiency will be practically that of the last amplifier—$\frac{3}{8}\varepsilon$ (from equation (10)) the same as for all modulator-amplifier systems.

8. MODULATING AMPLIFIER SYSTEM

Another system which falls under the head of modulation by amplification control is illustrated in Figure 19. This system has many characteristics in common with the van der Bijl system as well as with the rectifier system just mentioned. The circuit used is practically the same as for the van der Bijl system. An oscillator supplies a constant alternating potential to the grid of an amplifier while superimposed upon it is the signaling potential from the transmitter. The combination of the signal and radio frequency waves has approximately the same form as that applied to the rectifier system and shown in Figure 17.

The radio frequency is then variably repeated, or in other words, variably amplified in accordance with the audio signaling wave. The modulating amplifier system is an improvement upon the van der Bijl system in that the radio frequency voltage impressed upon the grid is equal to or greater in amplitude than the signaling voltage instead of being very much smaller, and also in the fact that it is possible to produce sufficient power to deliver directly to the antenna.

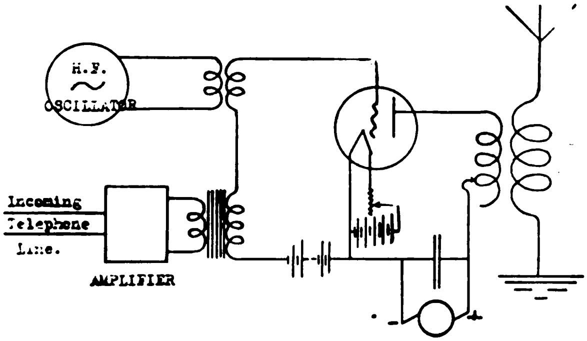

FIGURE 19—Modulating Amplifier Circuit

This system makes use of the unilateral amplifier characteristic of the audion. If we impress upon the grid of the modulating tube a constant negative potential plus the signalling and radio frequency wave of Figure 17, there will be produced in the plate circuit of the tube a current of practically the same wave form as the current thru the rectifier indicated in Figure 18. The constant negative potential applied to the grid is such that the space current is zero when no signal or radio frequency emf. is applied. Upon the application of the two voltages, the characteristic curve is operated upon to the extent that unidirectional pulses of space current flow, the magnitudes of which depend upon how much of the characteristic curve is operated upon. The antenna is tuned to take out the modulated radio frequency component and by-pass the harmonics and signal frequencies the same as in the rectifier system. The quality produced by this system is dependent upon the shape of the characteristic curve of the tube, and would work better if the tube had a straight line characteristic, or one of reversed curvature from that of the actual curve.

Some actual curves for a system of this kind are given in Figure 20. A radio frequency voltage of approximately 325 volts peak value was impressed upon the grids of the modulating amplifier tubes. The continuous potential applied to the grid was varied slowly while leaving the radio frequency voltage

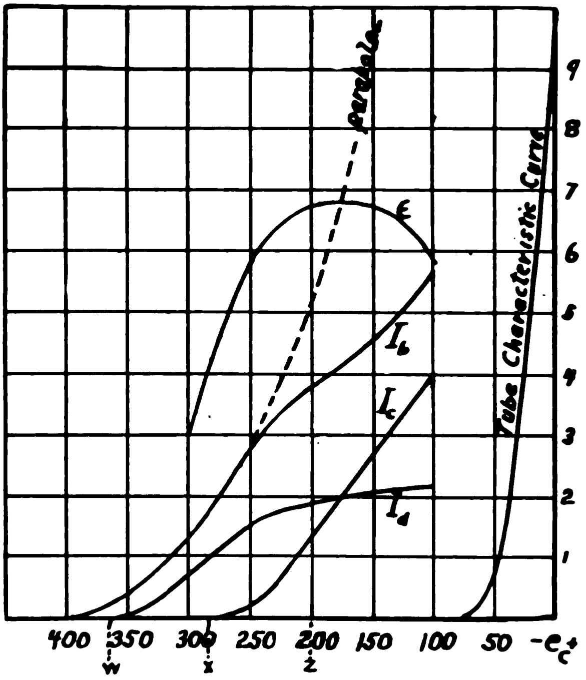

FIGURE 20—Operational and Control Curves of Modulating Amplifier

constant, giving the space, grid, and antenna current curves indicated. There is also shown the characteristic curve of the tubes themselves, and an efficiency curve for the plate circuit. These curves show that a signal voltage with a peak value of 80 volts will work over the entire desirable range on the curves and give a completely modulated radio frequency current.

The condition of operation is to apply a continuous negative potential of 280 volts to the grid, in which case there will be flowing antenna and space currents indicated by the letter *X* in Figure 20, and then impress at the same time a signal wave of 80 volts peak value. The point about which the radio frequency voltage varies is moved up and down these curves by the signalling voltage, going from 200 to 360 and giving in the antenna a modulated wave. Under the conditions mentioned, the antenna current will vary about a value of 1 ampere, rising to 1.9 and decreasing to zero. A completely modulated, tho slightly distorted antenna current is thus secured.

In a discussion of the theory and efficiency of this system, it is difficult to express the behavior mathematically due to the shape of these curves. An inspection shows that over the range of operation referred to (W to Z), the curves do not vary widely from straight lines. If we assume theoretical straight line curves for the control, space current, and efficiency curves, we can write equations which will express simply the behavior of the circuit. Theoretical curves of this kind are shown in Figure 21. The actual curves are shown dotted. The deviation of the actual from the theoretical curves is not great in the case of the control and space current curves, tho it is a little greater in the case of the efficiency curves. Time curves of antenna currents due to the theoretical and actual control curves are given in Figure 22. These show that the deviation of the actual curve from the theoretical is so slight as to affect by but a small percentage any computations we may make. Comparison of actual and theoretical space current curves shows a like result. For the purpose of pointing out the efficiency and power in this system, the hypothetical straight line curves of Figure 21 will be used.

Suppose we represent the space current when signaling by the equation

$$i = I_b \, (1 + sin \, \psi \, t) \tag{14}$$

where I_b is the average current flowing thru the tube. $Sin \, \psi \, t$ represents the signal wave. This assumes that the signal emf. upon the grid is such as to give complete modulation. As the plate voltage is constant the power to the modulating amplifier is

$$P_0 = E_b \, I_b \, (1 + sin \, \psi \, t) \tag{15}$$

The average power supplied to the amplifier will be the integral of this curve over a cycle and is given by

$$P = E_b \, I_b \tag{16}$$

The form of the curve for the radio frequency power to the antenna was given in Figure 3 and shown to consist of a single and double frequency components of signal wave frequency. The radio frequency power to the antenna in this case will be the product of efficiency of the amplifier and the power supplied to it. The efficiency from an inspection of the theoretical curve assumed in Figure 21 is observed to be expressed by the equation:

$$eff = \frac{\varepsilon}{2}(1 + \sin \psi t) \tag{17}$$

where ε is the plate circuit efficiency at the point so marked

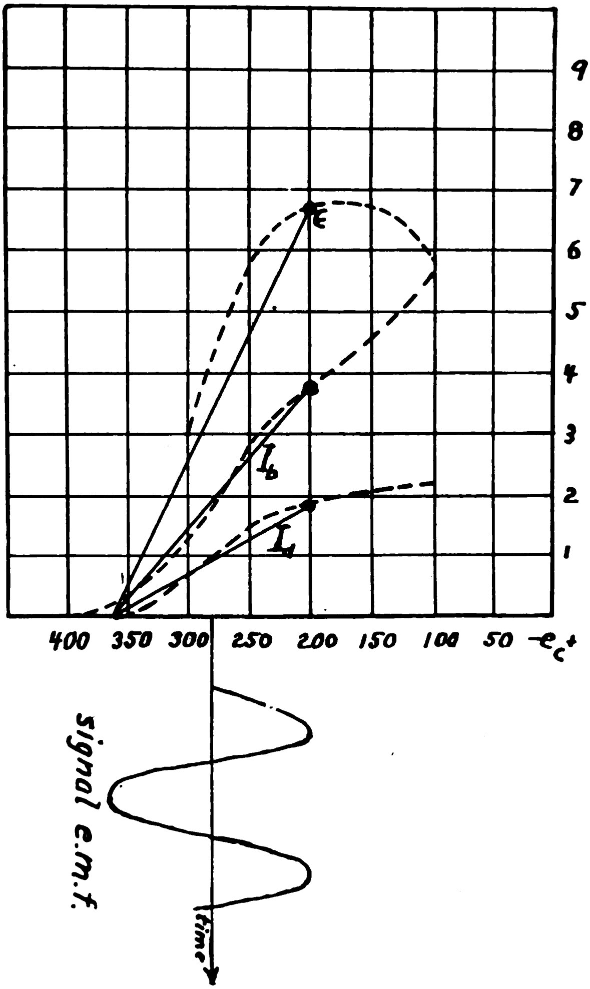

FIGURE 21—Theoretical Operational and Control Curves for Modulating Amplifier—Whole Lines. Actual Curves are Dotted

in the figure. By multiplying this by equation (15), we get the expression for radio frequency power in the antenna:

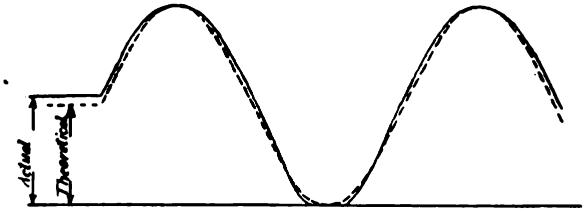

FIGURE 22—Antenna Current Amplitude Curves from Theoretical and Actual Control Curves.

$$P_h = \varepsilon \frac{E_b I_b}{2} (1 + \sin \Psi t)^2 \tag{18}$$

which will be observed to be identical in form with that given previously. This equation for power when integrated over a complete cycle gives

$$P_e = \frac{3}{4} \varepsilon E_b I_b \tag{19}$$

The steady power supplied at all times is equal to $E_b I_b$ and the coefficient $\frac{3}{4} \varepsilon$ gives the efficiency of the system as a generator and modulator combined. ε, which is the maximum efficiency of the plate circuit of the amplifier, can have values as high as 80 or 90 percent. It is common to have values over 60 percent. The efficiency of the modulating amplifier is therefore from 45 to 60 percent while modulating, that is, 45 to 60 percent of the direct current power supplied to the modulating amplifier is delivered to the antenna circuit in the form of modulated radio frequency current. This efficiency is as good as is secured with any other vacuum tube system.

This system of modulation was used in some experimental radio sets built for the United States Navy in 1916 and 1917. They were described generally as the multiplex set in the paper of Messrs. Craft and Colpitts mentioned previously. A schematic diagram of the transmitter arrangement is given in Figure 23. In this multiplex set, the intermediate frequency is modulated by the signaling frequency. This intermediate frequency is above the range occurring in the human voice, being in the sets constructed 25,000 to 45,000 cycles. A carrier wave of

238 meters (1,260,000 cycles) is then modulated by the signally modulated intermediate frequency and radiated. Modulation of the intermediate frequency by the signal, and of the radio frequency by the intermediate frequency is accomplished by this system.

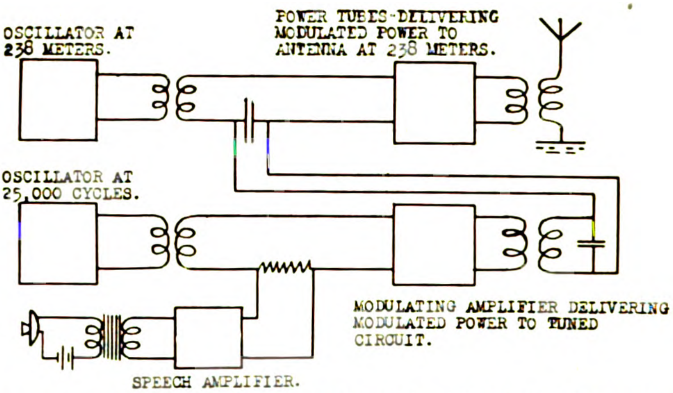

FIGURE 23—Schematic Diagram of Multiplex Modulating Arrangement

9. CONSTANT POTENTIAL AND CONSTANT CURRENT SYSTEMS

Two of the most efficient and satisfactory types of tube systems in use are the "constant potential" and "constant current" systems. In Figure 24 is shown the constant potential system (Patent number 1,137,315). It consists of a signal amplifier tube in series with a radio frequency amplifier tube. The signal amplifier tube, or modulator tube if it is wished to call it such, varies the power supply to the radio frequency amplifier tube according to a signal impressed upon the grid.

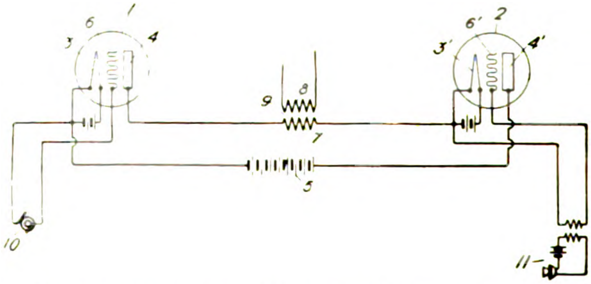

FIGURE 24—Constant Potential Modulating System

The latter tube, having a constant radio frequency voltage supplied to its grid, then converts this modulated power into radio frequency power, delivering a modulated radio frequency current directly to the antenna.

A more general schematic diagram for the constant potential system is given in Figure 25. An amplifier tube is connected in series with a frequency changer to which it delivers amplified power. The frequency changer to be used in this kind of a circuit is one which adds a frequency and not one which multiplies. Such a frequency changer sometimes used in power work consists of a rotor rotating inside a stator. The stator may have supplied to it polyphase power at a frequency f_2, and if the rotating field which it produces rotates oppositely to the direction of the rotor motion, the power delivered from the rotor is of a frequency equal to the sum of the supplied frequency f_2 and the natural frequency of rotation f_1, or it is f_1+f_2. If the polyphase power supplied to the stator rotates the field in the same direction as the rotor moves, that is with a frequency of $-f_2$, the resulting power will have a frequency of f_1-f_2. If direct current (zero frequency) is supplied, the resulting frequency will be $f_1+0=f_1$. If we supply to the stator a direct current and a polyphase current $+f_2$ we will have added to these frequencies the natural frequency of the frequency changer giving f_1 and f_1+f_2. Now it happens that a single phase current can be considered as the sum of two frequencies, that is, we may represent a sine wave by the equation

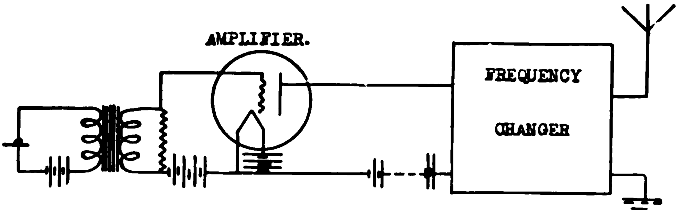

FIGURE 25—Constant Potential System

$$I \cos \omega t = \frac{I}{2}\left(\varepsilon^{+j\omega t} + \varepsilon^{-j\omega t}\right) \tag{20}$$

This equation indicates that we may consider a simple sine wave as being the sum of two independent alternating currents equal in amplitude, equal in their numerical values of frequency, but one a positive and the other a negative frequency. A single phase applied to a stator will produce an alternating field inside of it, which alternating field can be considered as produced by two polyphase currents which rotate their fields in opposite directions. If we apply to the stator direct current and single phase current we will get out of the rotor the same frequencies as tho we applied a direct current and positive and negative frequencies, that is, we will get f_1, f_1+f_2, and f_1-f_2. This behavior of the frequency changer provides a manner of producing modulated radio frequency current without the actual modulating of the radio frequency current by a modulator.

For radio purposes, we may use a frequency changer the natural frequency of which is the carrier wave desired, such as $f_1=25{,}000$ cycles. From an amplifier there is supplied a multitude of single phase frequencies f_2, f_3, and so on, in the speech signal and each single phase may be said to consist of $+f_2$, $-f_2$, or $+f_3$, $-f_3$, and so on. When these single phase currents, together with the direct current or zero frequency are supplied to the frequency changer, we have delivered to the antenna frequencies of 25,000 cycles plus all of those supplied, or

$$\begin{array}{l} 25{,}000 \\ 25{,}000+f_2 \\ 25{,}000-f_2 \\ 25{,}000+f_3 \\ 25{,}000-f_3 \\ \ldots\ldots\ldots\ldots \end{array}$$

The combination of these frequencies, it will be observed, constitutes a radio frequency current modulated by the signal frequencies f_2, f_3 and so on.

It is not necessary to go to a mechanical generator or frequency changer to accomplish this result, as it can be secured electrically by using an audion generator. In Figure 25 is shown an amplifier delivering power to an audion frequency changer. Zero frequency comes from the battery E_b and is the average direct current flowing thru the audions. The amplifier tube under the influence of a signal impressed upon this grid, delivers plus and minus speech frequencies in the form of single phase currents to the frequency changer which latter adds to all of them a carrier frequency f_1 thereby producing in the antenna a modulated radio frequency current, or a combination of currents of the frequencies f_1, f_1+f_2, f_1-f_2, $f_1\pm$ . . . .

This describes in general the principle upon which the constant potential as well as the constant current system operates, but it is desirable for several reasons to go deeper into the circuit's behavior, and analyze its operation. A study of the characteristic, behavior, and operational curves of the amplifier and generator points out many things which are of great value.

Take for instance the circuit as shown in Figure 25 and impress a signal upon the grid of the amplifier. The variation in grid potential varies the current to the two tubes in series by virtue of the variable resistance of the amplifier. The potential of the battery E_b is constant, but the drop across the amplifier and generator varies as the signal operates upon the amplifier grid. In Figure 26, the top horizontal line represents the battery voltage. Under the non-signaling condition, the voltage drops across the amplifier, E_a, and the generator, E_g, are equal. As the potential of the amplifier grid varies, the voltage drops across the two tubes change according to the curved line. The voltage drop across the generator thus varies between approximately zero and twice the non-signaling value when a completely modulated wave is being sent. The voltage across the amplifier varies in a similar way, but is maximum when that across the generator is minimum, and vice versa. As the voltages across these elements change, the current does also. As the amplifier grid has its potential changed in a positive direction, the effective resistance of the tube decreases and the current increases. The reverse occurs when the grid potential is varied in the other direction. The variation in potential across the generator causes the power taken by it to vary and also causes it to deliver a variable amplitude radio frequency current to the antenna.

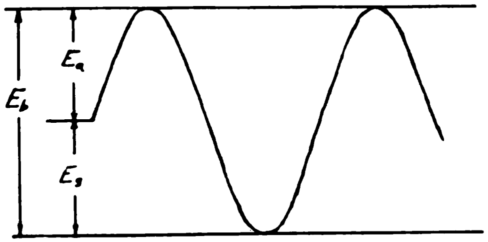

FIGURE 26—Voltage Distribution Between Amplifier and Generator of Constant Potential System

In the constant potential system just described, the source of power E_b supplies a variable current at a constant potential. The converse of this system is one which supplies a constant current at a variable potential. The latter system is described briefly in the paper by Messrs. Craft and Colpitts mentioned before. The circuit diagram is given in Figure 27.

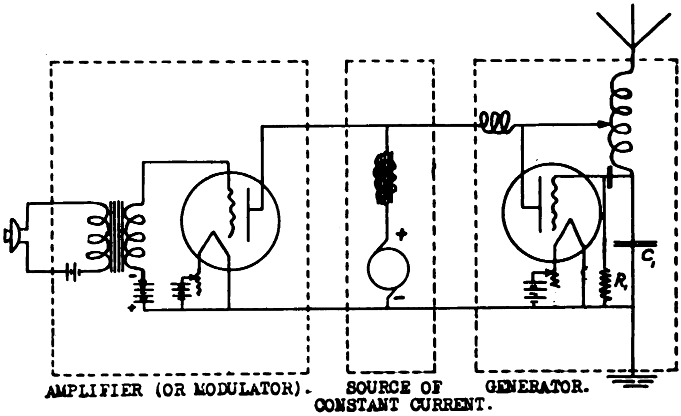

FIGURE 27—Constant Current System Circuit

The generator and amplifier in this case are connected in parallel with a constant current source of supply. This source of supply may be of any form desired, but its simplest and most satisfactory form is that of a constant potential generator or battery and a large choke coil. The constant current supply needs to be constant, or substantially so, in respect to speech frequency variations only. Variations due to change in the generator voltage, change in amplitude of signals, change in antenna resistance, and for very low frequencies such as will not disturb the ear, do not necessarily have to be prevented. It is only variations in current of the order of frequencies occurring in the signal which should be prevented from occurring thru the direct current generator.

The division of the current to the amplifier and oscillator in the constant current system is shown in Figure 28. The total constant space current is I_b, which is the sum of the oscillator current I_o and the amplifier current I_m. When a sine wave signal is transmitted, the currents vary according to the curved line. Distances above the curved line represent amplifier current and those below represent oscillator current. Such a variation in the division of the constant current causes the voltage across the tubes to vary. The variation in the current to the amplifier is caused by the signal being impressed upon the grid while that to the oscillator is caused by that part of the constant current taken only by the amplifier being varied. As a result of the presence of the choke coil a variation of amplifier current causes an inverse change in oscillator current, and with it a change in voltage. A curve of oscillator space current as a function of its plate voltage is shown in Figure 29. This curve is a straight line thruout almost its entire length, which means that the voltage of the oscillator must vary in practically the same manner as does the current. If the current to the oscillator

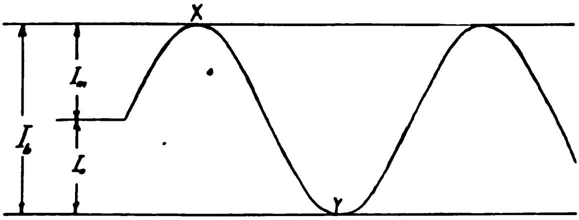

FIGURE 28—Division of Current Between Amplifier and Generator in the Constant Current System

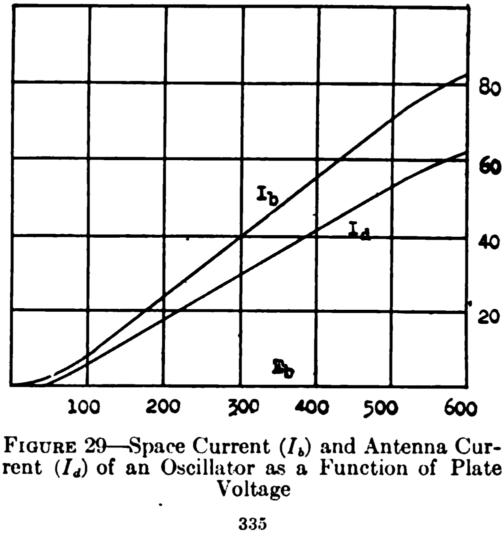

FIGURE 29—Space Current (I_b) and Antenna Current (I_d) of an Oscillator as a Function of Plate Voltage

is caused by the signal impressed upon the amplifier to take the form

$$i=I_o\,(1+K\sin\psi t) \tag{21}$$

and shown in Figure 28, the voltage across the oscillator must necessarily be represented by a similar equation for the reasons just mentioned and may be represented by the following which is plotted in Figure 30.

$$e=E_b\,(1+K\sin\psi t) \tag{22}$$

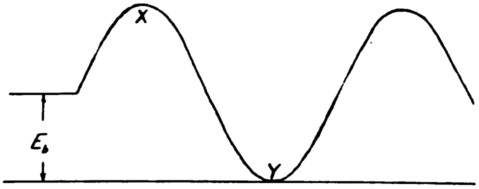

FIGURE 30—Voltage Across Oscillator when Current Varies as in Figure 28

The power supplied to the oscillator is the product of the current and the voltage or

$$\begin{aligned} e\,i&=E_b\,I_o\,(1+K\sin\psi t)^2 \\ &=E_b\,I_o\left(1+2\,K\sin\psi t+\frac{K^2}{2}-\frac{K^2\cos 2\,\psi t}{2}\right) \end{aligned} \tag{23}$$

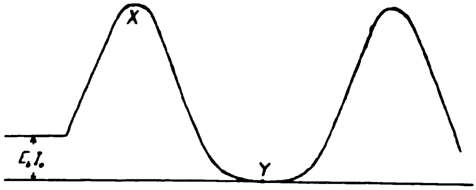

FIGURE 31—Power to Oscillator When Signaling

This equation is plotted in Figure 31. An interesting fact to be observed from this equation and curve is that the power to the oscillator when the modulation is complete ($K=1$) rises at one point to four times the power taken by it when no signal is being sent and to twice the average value taken by both the oscillator and amplifier. The power at other points drops to zero.

Inspection of the equation shows also that the average power over an audio frequency cycle is 50 percent greater than the power taken when no signal is being sent. It also shows that the power consists of single and double frequency components of the speech frequency exactly as does the power represented by the antenna current shown in Figure 3.

The power taken by the amplifier is somewhat different. The voltage across the oscillator is also the voltage across the amplifier. The current to the amplifier, however is represented by the distance between the top horizontal and curved lines in Figure 28, and is given by the equation.

$$i_m = I_m\,(1 - K\sin\psi t) \tag{24}$$

The power will be the product of the voltage and current or

$$e\,i_m = E_b\,I_m\,(1 - K^2\sin^2\psi t) = E_b\,I_m\left(1 - \frac{K^2}{2} + \frac{K^2\cos 2\psi t}{2}\right) \tag{25}$$

which is plotted in Figure 32 for a value of K equal to unity.

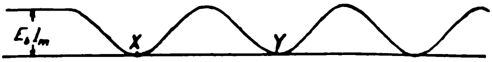

FIGURE 32—Power to Modulator when Signaling

It will be observed here that the power absorbed by the amplifier is a double frequency only of the signaling frequency, that it is a maximum at the time no signal is being sent, and that it has an average value of one-half the maximum when a completely modulating signal is being sent. The power absorbed by the amplifier is zero at the instant that the maximum power is delivered to the oscillator (X in Figures 31 and 32) and is also zero at the time that none is delivered to the oscillator (Y in the same figures). It indicates that there is more heat energy dissipated in the amplifier when not signaling than while signaling. These equations and statements are based upon the assumption that the modulator resistance can be reduced to zero by making the grid positive. Actually, this cannot be accomplished, but it can be reduced sufficiently to give complete modulation and conclusions arrived at by considering this assumption are not far wrong.

The efficiency of the modulating system as such is given by the equation of the power to the oscillator integrated over a cycle divided by the total power from the B battery or

$$eff=\frac{\int_0^{2\pi}\left[E_b I_o\left(1+2K\sin\Psi t+\frac{K^2}{2}-\frac{K^2}{2}\cos 2\Psi t\right)\right]dt}{E_b(I_o+I_m)}$$

$$=\frac{E_b I_o\left(1+\frac{K^2}{2}\right)}{E_b(I_o+I_m)} \tag{26}$$

If K is unity, which is the condition of transmitting a completely modulated wave, the efficiency is $\frac{3}{4}$, that is, *three-quarters of the direct current power from the constant current source goes to the oscillator notwithstanding the fact that the direct current instruments indicate that only one-half does.* Under the conditions of K less than unity, the efficiency of course is reduced, becoming one-half when no signal is being transmitted.

If the plate circuit efficiency of the oscillator is ε, the efficiency of the entire radio system (neglecting filament power) is $\frac{3}{4}\varepsilon$. The value ε can have may be anything up to 80 or 90 percent, the same as previously mentioned for amplifiers. An oscillator running on 300 volts E_b may have an efficiency of 60 percent and one constructed for higher voltages may reach the higher figures mentioned. The efficiency of the entire system may, therefore, reach values of 60 to 70 percent, which is quite high for a radio system.

10. COMPARATIVE EFFICIENCY AND PRACTICABILITY

On comparing the efficiencies of these systems, it will be observed that the constant potential, constant current, and modulating amplifier systems are most efficient and theoretically equal. Amplifier systems all fall below by various amounts down to an efficiency one-half that of the others. Control of generation systems at present known run from an equal value down to very small amounts instead of being better. From the point of view of efficiency, we would choose one of the three most efficient mentioned.

As regards quality or distortion, the constant current and constant potential systems are better than the modulating amplifier. The distortion in the modulating amplifier is produced right in the generator of the radio frequency and is difficult or impossible to eliminate, while in the others, what there is, is produced in the modulator and in many cases can be kept out of the oscillator by suitable circuits. The controlled oscillators known distort also, and the harmonics of the signaling frequency either cannot be eliminated, or if eliminated, it is done with considerable power loss. Amplifier systems, where a small amount of power is modulated, can have harmonics of the signal frequencies reduced sufficiently by operating on the small amount of power modulated, and then amplifying with a distortionless amplifier. However, an efficient distortionless amplifier of power is hard to construct and adjust and the efficiency of it may fall below 25 percent. These considerations, tho not of great importance now, may be more important in the future when the width of a transmitted band may be limited.

A factor affecting the practicability of these systems is the voltage at which they operate. Some work on lower or higher voltages than others. This comparison is based upon using the same type and number of tubes to get the same power into the antenna. The van der Bijl system, the modulating amplifier system, and the controlled oscillator system require $\sqrt{2}$ times the plate voltage needed for the constant current system. This is because these three systems require all the tubes to deliver a maximum power to the antenna at the normal voltage while the constant current system delivers the same maximum power from one-half the tubes at the instant the modulator and choke coil deliver double oscillator current and double voltage (X in Figures 28 and 31) to the oscillator. The voltage to the first three systems mentioned is constant while to the oscillator in the constant current system, it varies between zero and twice the average.

This may be expressed in a simple manner with a few equations and show what is hard to explain without them. If I is the space current taken by one oscillator tube (or the amplifier tube in a two tube constant current set), at voltage V, the power delivered to the antenna circuit from the one oscillator tube is

$$p = VI\varepsilon \qquad (27)$$

The peak power when modulating is four times this amount or

$$P = 4VI\varepsilon \qquad (28)$$

If the same two tubes (oscillator and modulator tubes) are used instead in an amplifier system or a controlled oscillator system running at voltage E, the space current per tube will be

$$i = I\frac{E}{V} \qquad (29)$$

as the tubes under maximum power conditions have space currents proportional to the plate voltage (very nearly) whether used as oscillators or power amplifiers. The same maximum power is to be delivered to the antenna circuit at the same efficiency by *both* tubes instead of one or

$$P=4\,V\,I\,\varepsilon=2\,i\,E\,\varepsilon=2\frac{I\,E}{V}E\,\varepsilon \qquad (30)$$

giving

$$2\,V^2=E^2 \quad \text{or} \quad E=\sqrt{2}\,V \qquad (31)$$

to give the same modulated power from the same number of similar tubes in an amplifier or controlled oscillator system as is needed for the constant current system.

The constant potential system, of course, requires twice the voltage needed for the constant current system. The use of the lower voltage alone, in many cases, is a most important factor in determining the most desirable system to use.

11. CONCLUSION

The five or six modulation systems discussed in this paper must not be taken as the only ones possible. The possible combinations of tubes, circuits, and microphones which will produce modulated radio frequency currents, seem unlimited. They do however, become more complex, are more difficult to adjust, or are less efficient. In principle, most will fall under the classes described or combinations of them.

No general principle can be stated which covers all radio systems. Some are truly modulation systems while some are systems for producing modulated power. Since the production of modulated power is the ultimate object to be secured in a radio system, all classes have been included in this paper. New methods of generation will undoubtedly be invented in the future and also new methods of modulation giving combinations to be added to those mentioned.

ADDENDUM

In the main part of this paper, many important facts concerning the constant current system are omitted to avoid covering up the main points. The wide use of the system makes it desirable to present many of the omitted facts because they are of value both to a better understanding of the theory, and in designing and building sets.

The oscillator and its operation has been described by the writer in another publication[3] but it appears desirable to point out and emphasize certain facts concerning it which are of importance in a radio telephone set. Two of these facts are observable by referring to the curves in Figure 29. These curves represent space and antenna currents of a properly constructed oscillator as a function of plate voltage. They are straight lines except at the extreme ends. Over the most used part of the curves, they are straight lines, which fact insures that if the current to the oscillator is made to take the wave form of a signal, the voltage across the oscillator will also have that wave form, and if the voltage has the signal wave form, the amplitude of the antenna current must have the signal wave form. These two straight line operational curves are thus important characteristics desirable in a set on account of the distortionless modulation obtained.

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[3] "The Audion Oscillator," "Journal of the American Institute of Electrical Engineers," April and May, 1920.

It is not absolutely necessary that the curves be straight lines to secure a distortionless output, as the latter can be secured if the curves are alike. That is, the space current and antenna current curves must be expressable by the same type of equation tho with different constants. A distortionless modulated current is then secured having the modulation form of the *oscillator current supplied.*

This manner of securing a distortionless output is not as desirable as the arrangement having straight line operational curves. The latter causes the oscillator to behave like a pure resistance to currents sent in by the modulator, while the curved curves cause the oscillator to act as a variable resistance, the value of which is a function of the current. The desirability of an oscillator behaving as a variable resistance depends upon the type of modulator or other source of signal power. It may produce a distortion all of its own and not allow the current to the oscillator to have the wave form of the signal to the modulator.

To secure the desired straight line curves for an oscillator, two requirements must be observed. They are:

1. The tube must operate above temperature saturation for the filament.

2. A grid stopping condenser and leak resistance must be used.

The type of oscillator circuit used is immaterial as all give the same results when properly adjusted.

The curvatures in the operational curves of Figure 29 are from two causes. That at the lower end is on account of the tube impedance rising rapidly at the low voltage, and that at the upper end (occasionally) is caused by lack of temperature saturation at that voltage.

In separately excited generators, such as shown in Figure 24, the operational curve is not a straight line. The constant radio frequency voltage on the grid does not give space and antenna currents proportional to the plate voltage. To make these curves straight, it is necessary to use the modified circuit shown in Figure 33. The reason this generator has straight line curves like an oscillator is as follows. An oscillator, which has a straight line curve, has a grid voltage proportional to the plate voltage, because the antenna current which produces the grid voltage is proportional to the plate voltage. By making the exciting oscillator have its plate voltage vary the same as that of the generator tube, radio frequency output from the exciting oscillator, which is also the generator tube input, will be proportional to the plate voltage. The input conditions of an oscillator are thus secured for the separately excited tube.

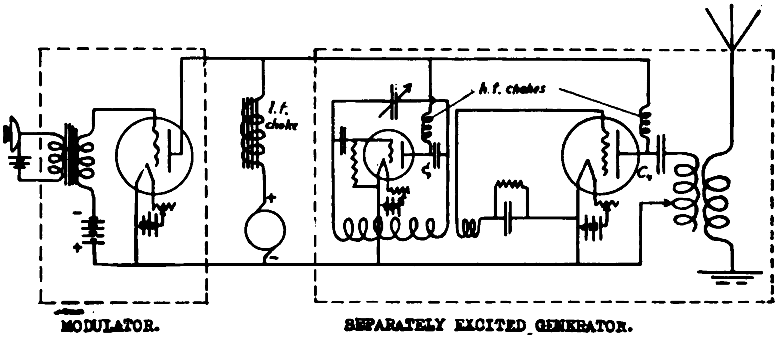

FIGURE 33—System Using Separately Excited Generator with the Exciting Oscillator also Controlled

In the discussion within the paper, the oscillator or generator efficiency ε was assumed as constant. As the plate voltage of an oscillator varies, the efficiency varies as shown in Figure 34. Over the larger part of the range of operation the efficiency does not vary greatly, and we are not unjustified in assuming it constant in our discussion. This actual drop in efficiency at the lower values may be explained by referring to Figure 29. It will be observed that the antenna current curve strikes the axis at a value of E_b greater than 0. At this point the efficiency must necessarily be zero. If the curve were entirely straight and passed thru the origin, the efficiency would be nearly constant thruout the range. As it is, however, the efficiency rises rapidly with voltage from zero at the value of E_b at which oscillations start and approaches a nearly constant value as the plate voltage becomes large.

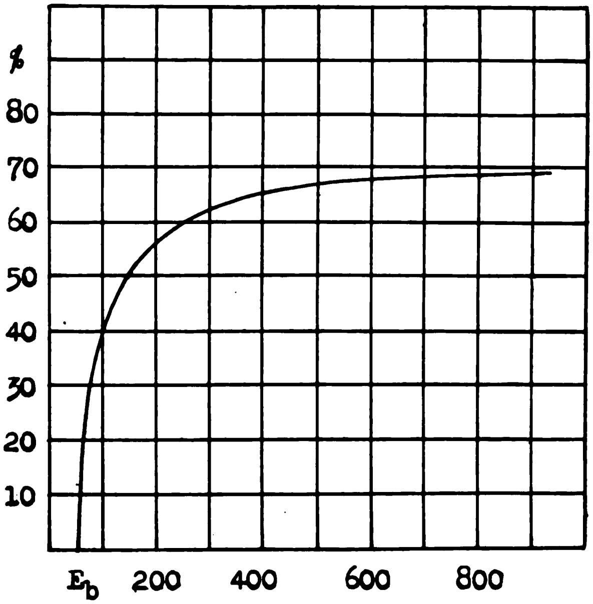

FIGURE 34—Efficiency of an Oscillator or Generator as a Function of Plate Voltage

The point at which we wish the greatest efficiency to occur is the point at which the maximum power is delivered to the antenna, that is, point *X* in Figure 31. If the efficiency drops a trifle for lower values of plate voltage, we need not concern ourselves greatly because we expect that the antenna current will drop to zero anyway at certain points, and under the conditions in this system at which it does, that is, point *Y* in Figures 31 and 32, the efficiency may be low, or may even be zero. However, the power delivered to both the oscillator and modulator at that instant is also exceedingly small, if not zero, and the low efficiency causes very little loss. During the rest of the time (between points *X* and *Y*), various moderate amounts of power are delivered to the oscillator, and the efficiency is nearly constant thruout most of it. The fact that the efficiency of the oscillator is practically constant thruout that part of the cycle when the largest amounts and the greatest part of the power are delivered to it, justifies us in our assumption of constant efficiency in any but a most exact discussion.

The design of an oscillator for a telephone set demands the proper proportioning of certain elements which may be of small importance for the oscillator only. One element is a condenser necessary to provide a radio frequency path from the plate to the filament and at the same time break that path for direct current. See C_1 in Figure 27 or C_4 in Figure 33. This condenser must also break the path for signal frequency currents so as to force them thru the tube, and therefore cannot be too large. If the condenser is very large, it by-passes some of the signaling current. Power meant for the oscillator is thus wasted. These condensers must be no larger than is necessary to conduct the alternating space current without producing an undesirable phase shift.

Another part of the circuit, the values of which may influence the operation of the set, is the grid leak circuit, that is the sizes of the grid stopping condenser and grid leak resistance. The negative voltage for the grid is caused by the grid current passing thru the grid leak resistance. This usually sets the value of the resistance. A negative charge is maintained by the grid stopping condenser for the grid. As the signal voltage is impressed upon the plate, it is necessary that the negative voltage for the grid vary also, otherwise uneven or intermittant oscillator operation will occur. To avoid this trouble, the stopping condenser should not be so large that it will maintain a charge that can not leak off the grid as fast as the plate voltage falls during a signal. It should not be so small as to introduce a phase shift to the grid, but should be of such a size that with the grid leak resistance it will form a circuit with a time constant much shorter than the period of the highest frequency in the signal. In most radio sets, no trouble is encountered in making these parts of proper size, but if the carrier and signal frequencies are too near the same (such as 15,000 and 2,000 cycles), these elements must be carefully considered.

The most convenient source of constant current for a set is a constant potential battery or generator and a large choke coil. The choke coil should theoretically have infinite inductance, but practically it may be small enough so that its inductive reactance at 800 cycles is 3 or 4 times the resistance of the oscillator or modulator. Making it larger increases the modulating efficiency, but the maximum possible obtainable is only approached asymptotically. If the choke coil has a reactance three times the resistance of the oscillator at 800 cycles, about 95 percent of the variation in current of that frequency produced by the modulator will pass thru the oscillator and 32 percent will pass thru the choke coil and battery "wattlessly." If the choke coil has a reactance twice that value, 98.6 percent of the current will pass thru the oscillator and 16.5 percent thru the choke coil and battery "wattlessly." Beyond these values, the increase in modulated current is very small compared to the increase in size of the choke coil, and practically is not worth trying to save.

When a direct current generator is used as the *B* circuit supply, its armature inductance is added to that of the choke coil in tending to maintain the current constant.

In the previous discussion of efficiency, no mention was made of an adjustment of the constant current system which increased its efficiency materially. The assumption was made that the non-signaling space current of the modulator equalled that of the oscillator. The non-signaling power efficiency is then $\frac{1}{2}\varepsilon$. In practice it has been the custom to make the modulator current one-half that of the oscillator current. The non-signaling efficiency is then $\frac{2}{3}\varepsilon$. This adjustment is possible because when a signal is transmitted, the curved characteristic of the modulator causes the average modulator current to rise to an equal value and the condition necessary for proper and complete modulation occurs. The efficiency of the set is thus $\frac{3}{4}\varepsilon$ when signaling and $\frac{2}{3}\varepsilon$ when not signaling.

In many radio sets it has been the practice to connect a resistance across the high side of the input signal transformer. The purpose of this resistance is twofold. (a) It improves the quality and (b) it stabilizes the amplifier or modulator circuit. It has always been the practice in telephone amplifier work to place a resistance across the input transformer for the maintenance of quality. An open circuited transformer, especially if connected to a capacity load, has a transformation ratio dependent upon the frequency. This distortion is analogous to that produced in a microphone due to the free period of the diafram. Such distortions, tho giving more volume, reduce the quality, often to a prohibitive degree. Building a microphone for better quality reduces the volume of energy given out materially, while building a transformer for the best quality seldom reduces it more than 50 percent. The practice has therefore been to tolerate the distortion produced in the microphone, but avoid the production of any in the circuit. A transformer designed to be used with a resistance across it can be made to produce no distortion in speech signals.

The modulator circuit, when not using a resistance across the transformer, can be looked upon as consisting of an inductance between filament and grid, with an inductive circuit between filament and plate. These inductances, together with the grid to plate capacity produces a Hartley type oscillator and oscillations may result. The resistance tends to prevent this.

Research Laboratory of The American Telephone and Telegraph Company, and the Western Electric Company, Incorporated, August 23, 1920.

SUMMARY: After considering the general characteristics of a voice-modulated radio frequency current, there is given a systematic classification of the various methods of producing such modulation in transmitters using three-electrode vacuum tubes.

The output, efficiency, stability, completeness of modulation, quality, and other characteristics of each method of modulation are studied.

The apparatus and circuits used in the long distance radiophone tests at Arlington, Virginia, in 1915, are described.

APPENDIX

The question has been asked why an amplifier system has a lower efficiency than the modulating amplifier system when there appears, looking at them broadly, to be no fundamental reason for it. In answer, it should be stated that it is largely a question of quality desired and adjustment made which determine this difference. I shall endeavor to point out the underlying causes and varying modifications which produce the difference.

Before beginning the direct comparison, it appears wise to define two types of amplifiers—the "proper amplifier," and the "improper amplifier." By a proper amplifier is meant one which has a constant negative potential of such an amount applied to the grid that the operating point falls upon the static characteristic curve. This is represented in Figure 35 where the negative grid potential e_c establishes the point P_o as the operating point. The dynamic characteristic curve of the tube and circuit is also represented. The input modulated radio frequency wave to be amplified is represented with the time axis running downward, and the resulting space current is represented with its axis running to the right. Amplifiers for telephone work are constructed upon this principle as they give very little distortion.

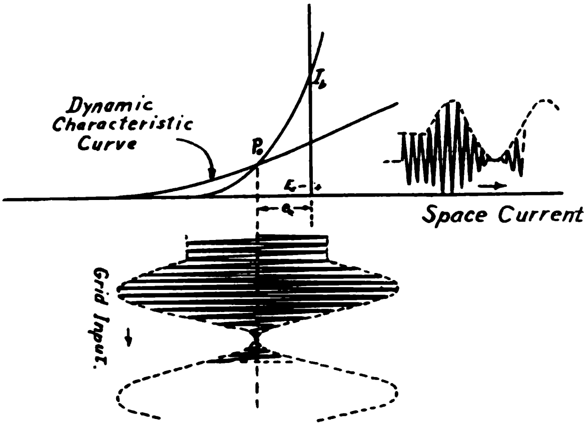

FIGURE 35—Operating Scheme of a Proper Amplifier

By an improper amplifier is meant one which has such a large negative grid potential as to cause the operating point to be a considerable distance to the left of the bottom of the static characteristic curve. The value of this negative potential may be several times the value at which the static characteristic strikes the *X* axis. This is represented in Figure 36. A different type of input wave is also used, and a different type of output current is secured. The dynamic characteristic, instead of being a single curve as in the proper amplifier, is a family of curves. Each curve of the family is a function of the amplitude of the input voltage wave as well as of the tube and attached circuit constants. The result is that a varying amplitude wave of the radio telephone class uses a whole family of these dynamic curves. The output of this amplifier is not the same as the input. An enormous distortion of the modulated wave itself is caused, as can be seen by comparing the modulated component of the space current with the input wave. Likewise, a pulsating space current of the modulating frequency occurs which is many times larger than that produced by the curvature of the characteristic curve in the proper amplifier. With this type of amplifier, an incompletely modulated wave is impressed upon the grid, and the action of the amplifier is such as to deliver a completely modulated wave to the antenna. However, a study of the system will show that considerable distortion of the modulating signal is produced. Tho this distortion is greater than in the proper amplifier, it is not any greater than that produced in the modulating amplifier.

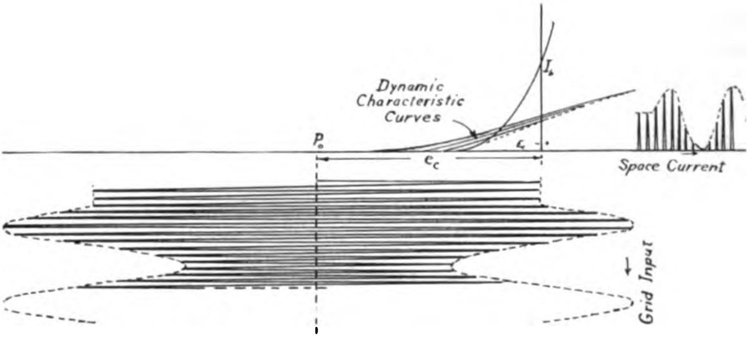

FIGURE 36—Operating Scheme of a High Efficiency Improper Amplifier

In the comparison in the paper of amplifier systems with the modulating amplifier and constant current systems, a proper amplifier was assumed. One of the causes of the great difference in efficiency can be seen by a reference to Figure 37. It is desired to produce in the antenna modulated radio frequency power represented by curve I which is the power curve for a wave modulated by a single sine signal wave. An assumption is now made, for the purpose of simplifying the comparison, that the proper amplifier can deliver its maximum power with the same plate circuit efficiency as can the modulating amplifier. Such

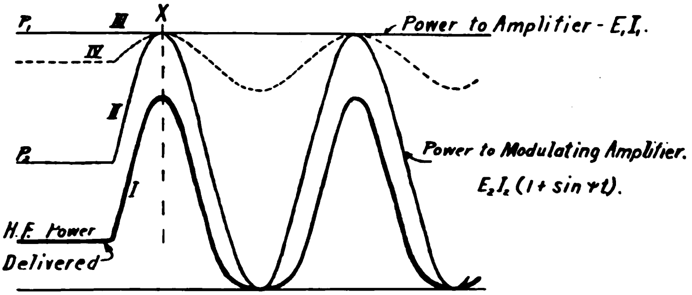

FIGURE 37—Power Curves for the Modulating Amplifier (II) and Proper Amplifier (III and IV)

an assumption is to the advantage of the proper amplifier, and makes the discrepancy between the resulting efficiencies greater than is determined from this comparison. The point at which the efficiencies are assumed equal is marked X in the figure. At that instant both systems can deliver the desired radio frequency power with the same plate input. The plate input needed is indicated as P_1. If a second assumption is made—that the tube has a straight line characteristic curve—the horizontal line, curve III, is the curve of power taken by the proper amplifier while delivering the desired modulated radio frequency power to the antenna. If this second assumption is not made, the dotted line, curve IV, is the power taken in during the same time. The variation in power in this case is caused by a variation in plate current as a result of the curved characteristic curve of the tube. In the modulating amplifier, the same power P_1 must be taken in at the instant marked X, but since the tube has the signal wave impressed upon its grid, as well as the radio frequency, the space current is varied according to the signal and the power taken is represented by curve II and expressed by equation 15 in the paper. The result is that by comparing the power represented by curves II and III, that is, by comparing the areas under these curves, the proper amplifier is observed to take twice the power and yet deliver the same amount of power to the antenna. This gives it only one-half the efficiency of the modulating amplifier. If curves II and IV are compared instead, which are the true inputs, the ratio of powers is reduced a trifle from the value of two.

Consideration of the cause of the variation in space current produced by the curved characteristic and its effect upon the efficiency as shown by using curve IV instead of curve III, lead us to an adjustment of the amplifier which brings the efficiency nearer to, and can be made equal to, that of the modulating amplifier. That is, by changing the adjustment, or other factors in the circuit so that the space current of the tube varies with the amplitude of the input radio frequency, the power input curve IV can be made to approach more and more closely to curve II until they coincide. This is accomplished by increasing the negative voltage on the grid until the operating point is moved to the left of the static characteristic curve, and changing the nature of the modulated radio frequency input so as still to give the desired output. When this is done it will be found that we have the conditions mentioned as existing in the improper amplifier, or as represented in Figure 36. In this case curve II stands, not only for the power input to the modulating amplifier, but for the power input to the improper amplifier, and the efficiencies of the two circuits are the same.

A factor to be considered in the comparison of the proper amplifier and the modulating amplifier is the plate circuit efficiency of the tube at maximum power. Plate circuit efficiency must not be confounded with the system efficiencies which are being compared. The system efficiencies being compared are secured by dividing the radio frequency power (modulated), integrated over a signal frequency cycle, by the plate power taken in (either steady or variable), integrated over the same cycle. By plate circuit efficiency is meant steady radio frequency power divided by steady plate power supplied. It is the same as radio frequency power, integrated over a small part of a signal period, divided by plate power taken in, integrated over the same short period. In the comparison first made, it was assumed that the plate circuit efficiencies of the modulating amplifier and proper amplifier were the same at the time *X* in Figure 37. The plate circuit efficiency of the modulating amplifier at this point may be 80 or even 90 percent, but the corresponding efficiency of the proper amplifier at that point is around 35 percent with a maximum possible of 50 percent.[4] This great discrepancy puts the proper amplifier at a still greater disadvantage than the ½ ratio pointed out. To get a high power efficiency in the plate circuit of a tube, the form of the radio frequency wave must be changed from a sine wave, or the method of applying it to the grid must be changed. In order to make the efficiency high, the sides of the input radio frequency wave must be made very steep to make the time during which the resistance of the tube is large but finite, extremely small, or else to cause the tube to have this variation in resistance at a time that the plate potential·has dropped to a low value. These requirements demand either a rectangular wave form for the radio frequency input, or such a large negative grid potential that only the peak of the sine wave operates upon the characteristic curve. The latter is the easier to do and is the manner in which the modulating amplifier, as well as the improper amplifier works. The result of using only a small part of the radio frequency wave upon the grid thus causes the tube to operate more as a shock exciter for the tuned circuit than as an amplifier (tho it can be considered as both) and the plate circuit efficiency may rise at the point X to the values mentioned—80 to 90 percent in extreme cases.

The proper amplifier is distinctly not a shock-exciting arrangement and the high efficiencies are never attained. With the attainable values around 35 percent, it is obvious that in Figure 37 the peak power delivered at X cannot be secured with an input of only power P_1. In fact, the proper amplifier will require approximately 2 P_1 input at that point to give the desired output and the average power taken in over a modulating cycle will be very close to that same value. The power curve during this cycle will have the form of curve IV, but twice the ordinates or more. In the modulating amplifier, due to the high efficiency at X, curve II represents the true power in, and P_2 (which equals ½ P_1) is the average power. Thus the proper amplifier with the combination of low plate circuit efficiency and a nearly constant space current during the modulating cycle gives an overall efficiency about ¼ that of the modulating amplifier with its high plate circuit efficiency and varying space current during the modulating cycle.

I might summarize the conclusions arrived at by saying that there are two reasons why a system using the proper amplifier is less efficient than the modulating amplifier system. The first is that the plate current of the proper amplifier is almost constant plate current during the modulating cycle while that of the modulating amplifier varies with the signal. The second is that the maximum plate circuit efficiency of the proper amplifier runs around 35 percent, while in the modulating amplifier it runs around 80 percent. The first reason gives the proper amplifier an over-all efficiency of a trifle over one-half that of the modulating amplifier, and the second reason gives it an over-all efficiency of less than one-half that of the modulating amplifier. The resulting efficiency is therefore around one-fourth that of the modulating amplifier. The efficiency of an amplifier system can be raised to that of the modulating amplifier system if we change the proper amplifier to an improper amplifier and apply an incompletely modulated wave to the grid. The efficiencies and distortions in the two cases will then be the same.

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[4] "The Audion Oscillator," "Journal of the American Institute of Electrical Engineers," R. A. Heising, May, 1920.

DIGEST OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

ISSUED APRIL 19, 1921-JUNE 14, 1921

BY

JOHN B. BRADY

(OURAY BUILDING, WASHINGTON, D. C.)

The object of this section in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS is to make available in convenient form for research engineers and others interested, brief information on radio patents which are issued each week by the Patent Office. The rapid development in this art emphasizes the importance of radio research engineers being familiar with patent literature to eliminate, as far as possible, the duplication of effort in research. It is not the purpose of this section to explain radio inventions fully, but merely to indicate the general nature of the patents in order that those of particular interest to individuals concerned with certain problems may be selected, and complete copies of the patents obtained for study. Copies of the patents may be secured at ten cents each by communicating with the Commissioner of Patents, Washington, D. C.

Reissue 15,089—Carl R. Englund, East Orange, New Jersey, original application filed March 11, 1916, patented as number 1,258,548, dated March 5, 1918. Application for reissue filed March 3, 1920, issued April 19, 1921. Assigned to American Telephone and Telegraph Company.

RADIOTELEPHONY. The patent relates to the modulation system wherein the carrier frequency is prevented from reaching the antenna at the transmitter and is renewed from a local source at the receiver for operation with the modulated energy.

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*Received by the Editor, June 27, 1921. While great care has been taken in the preparation of these Digests, THE INSTITUTE OF RADIO ENGINEERS assumes no responsibility for their correctness or completeness, or for possible omissions of particular patents.—EDITOR.

Fig. 1.

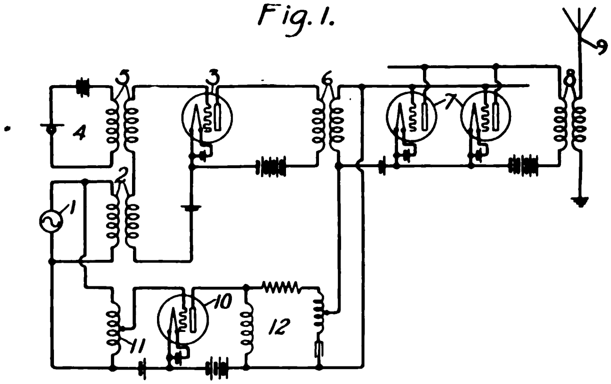
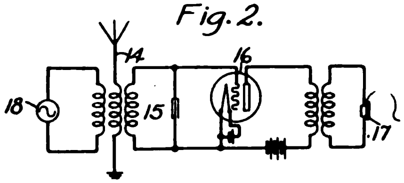


Fig. 2.



REISSUE 15,089—Radiotelephony

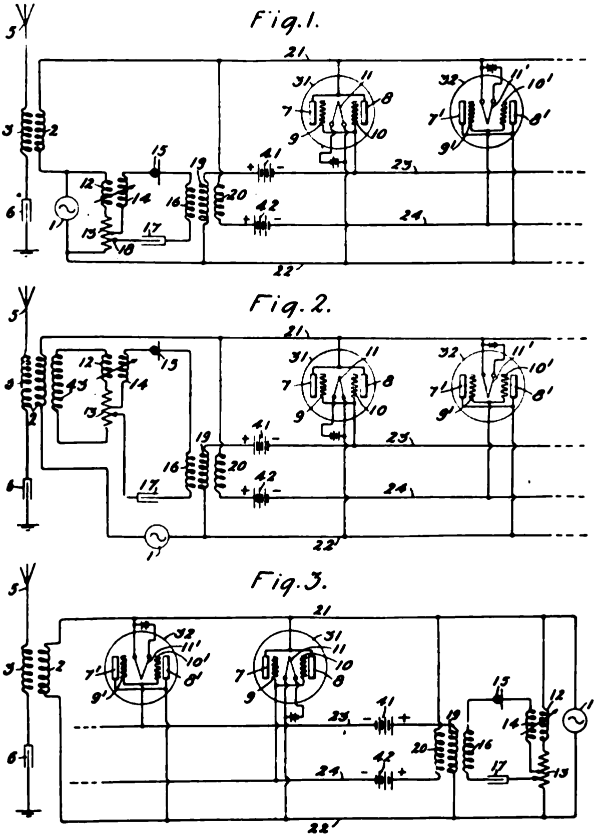
1,375,481—Harold D. Arnold, East Orange, New Jersey, filed August 23, 1915, issued April 19, 1921. Assigned to Western Electric Company.

1,375,982—Elihu Thompson, Lynn, Massachusetts, filed November 16, 1916, issued April 26, 1921. Assigned to General Electric Company.

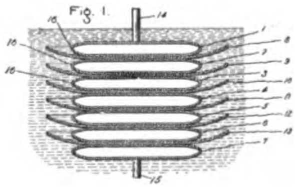
CONDENSER comprising a series of electrodes of greater thickness than the dielectric which separates them, each of the electrodes having rounded edges in such a way that there is a gradual tapering away of the surface of the electrode from the dielectric, thereby avoiding the formation of corona discharges at the edges of the electrodes.

1,375,992—Ernst F. W. Alexanderson, Schenectady, New York, filed April 18, 1919, issued April 26, 1921. Assigned to General Electric Company.

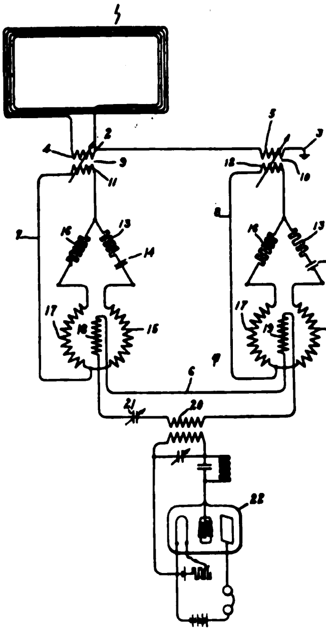
RADIO-RECEIVING SYSTEM comprising an antenna circuit containing currents due to electromagnetic exposure and an electrostatic exposure. The receiving circuit associated with the antenna consists of two aperiodic intermediate circuits, each comprising two portions having different phase angle characteristics. The two portions of each intermediate circuit are coupled with the receiver and may be varied to change the phase of the currents impressed on the receiving circuit.



Number 1,375,481—Power-Modulator for Radio Transmission

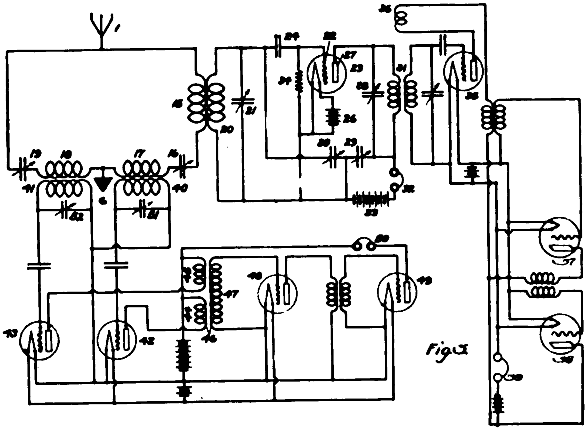


Number 1,375,982—Condenser



NUMBER 1,375,992—Radio-Receiving System

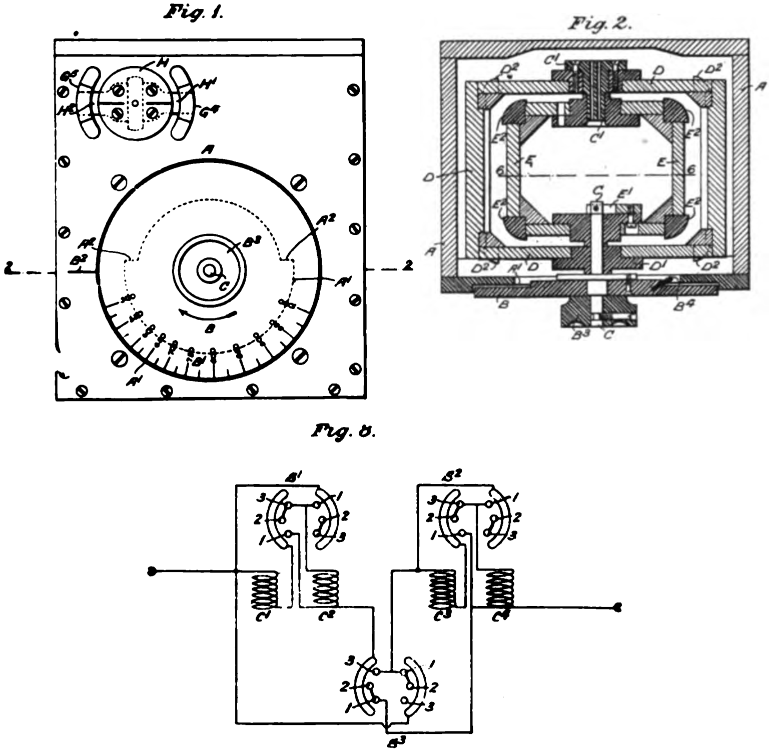
1,376,051—Albert Hoyt Taylor, Grand Forks, North Dakota filed April 10, 1919; issued April 26. 1921.



NUMBER 1,376,051—Simultaneous Transmission or Reception of Speech and Signals

SIMULTANEOUS TRANSMISSION OR RECEPTION OF SPEECH AND SIGNALS in which the transmitter emits two widely different wave lengths with telegraph signals on one of the wave lengths and the telephone conversation intermittently on the two wave lengths. The receiver contains three oscillatory circuits, one of which receives the telegraph signals and the other two of which are arranged to combine the intermittent parts of the telephone conversation.

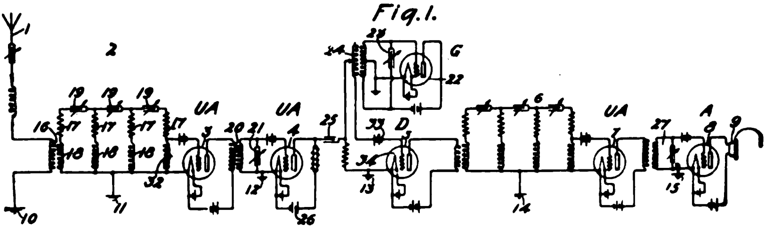
1,376,592—John Sealy Edward Townsend, Oxford, England, filed April 10, 1918, issued May 3, 1921.



Number 1,376,592—Variometer

1,376,679—Austen M. Curtis, Brooklyn, New York, filed October 10, 1917, issued May 3, 1921. Assigned to Western Electric Company.

Radio Receiving System in which the energy of static is converted into a form different from the form of the signaling energy or into a plurality of different forms of energy, only one of which corresponds to the signaling energy, the latter having a definite character to which the signaling receiving circuit is selective, so that the effect of the static is reduced in proportion to the conversion of the same into the form or forms to which the signaling receiving circuit is not responsive.



Number 1,376,679—Radio Receiving System

This is accomplished by using between the antenna and the signaling receiving device an intermediate network capable of oscillating at more than one frequency. An irregular electric wave, such as static, on striking the network will have a portion of its energy diverted to the production of the natural oscillations of the network. The more nearly the static approaches a pure impulse, the more nearly will it be completely changed into these natural oscillations. If the frequency of the continuous signaling wave is made to coincide with one of the natural frequencies of the network and a circuit sharply resonant to this frequency is non-reactively, that is, uni-directionally or loosely coupled to the network, the continuous wave and also oscillations of the natural frequency of the network which are caused by the impression of the static upon it, will be produced in the resonant circuit; but the natural frequencies of the network other than the one which is made to coincide with the continuous wave, will be almost completely suppressed. The continuous signaling wave will be reduced in amplitude by losses in the network and in the coupling. The static will be subject to losses which are similar altho different in magnitude, plus a loss caused by the fact that part of its energy has been used in the production of natural oscillations which are not appreciably transmitted to the resonant circuit.

1,377,059—Fulton Cutting, Tuxedo Park, New York, and Bowden Washington, Cambridge, Massachusetts, filed June 26, 1918, issued May 3, 1921.

Fig. 1

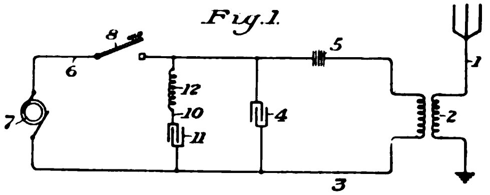
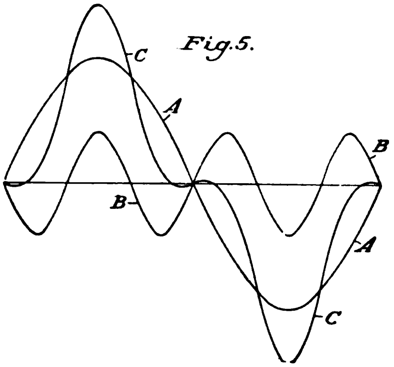


Fig. 5.

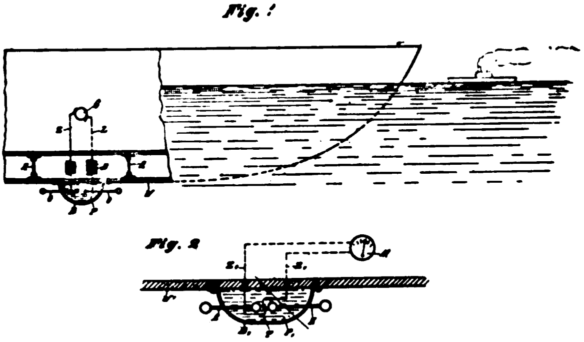


NUMBER 1,377,059—Production of Electrical Current Pulses

PRODUCTION OF ELECTRICAL CURRENT PULSES by a modification of the Chaffee system. The transmitter circuit includes an auxiliary circuit 10, 11, and 12 having a frequency of about three times the frequency of the alternator, which absorbs energy at the beginning and end of each wave or alternation of the current supplied by the alternator and restores energy during the middle of the wave, thus producing shortened and peaked waves separated by periods of substantially no activity. The alternator 7 impresses on the system an alternating current which is indicated by curve *A* (Figure 5). The current in the auxiliary circuit is represented by curve *B*. The resultant current represented by *C* is impressed on condenser 4 and is the algebraic sum of the currents *A* and *B*.

1,377,129—Walter Hahnemann, Kiel, Germany, filed January 2, 1915, issued May 3, 1921. Assigned to the firm Signal Gesellschaft m. b. H. of Kiel, Germany.

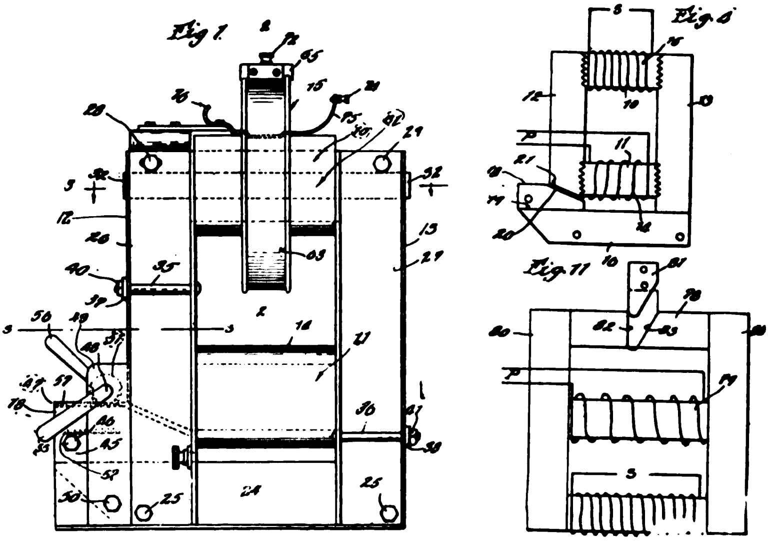
UNDERWATER WAVE TELEGRAPHY which utilizes a Hertzian oscillator on the hull of a ship having one of the ends of each electrode disposed in a receiver filled with an insulating fluid and with their other ends extending into the water outside.



Number 1,377,129—Underwater Wave Telegraphy

The oscillator is energized by a generator at the transmitter (Figure 1) and a similar oscillator employed at the receiver (Figure 2) connected with an indicating meter. The system utilizes an alternating current having a frequency of at least 3×10^8 per second, that is, such a frequency as to cause the capacity reactance of the transmitting medium at its highest value to be equal to the ohmic resistance of the medium.

1,378,151—Chester H. Thordarson, Chicago, Illinois, filed November 6, 1916, issued May 17, 1921.



Number 1,378,151—Electrical Transformer

Electrical Transformer of the closed core type with a movable core element for varying the magnetic flux of the transformer core thereby to vary the input of the transformer and to vary its output correspondingly.

1,378,345—Roy Edwin Hall, Chicago, Illinois, filed May 31, 1919, issued May 17, 1921. Assigned to Hall Research Corporation.

Fig. 3.

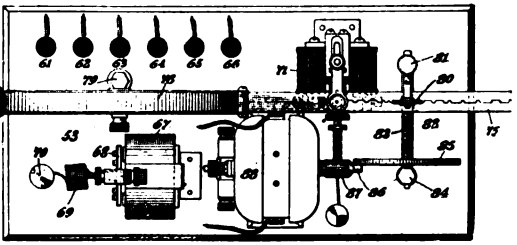


Fig. 4.

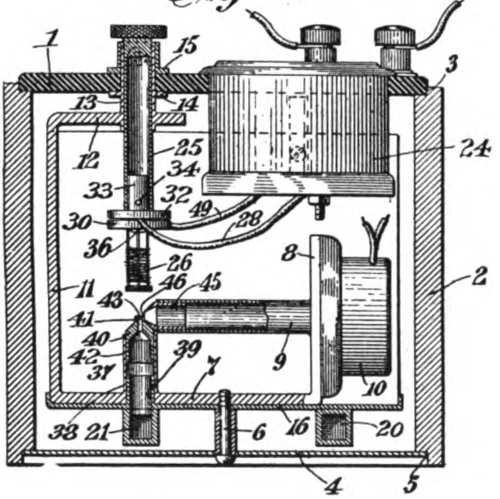
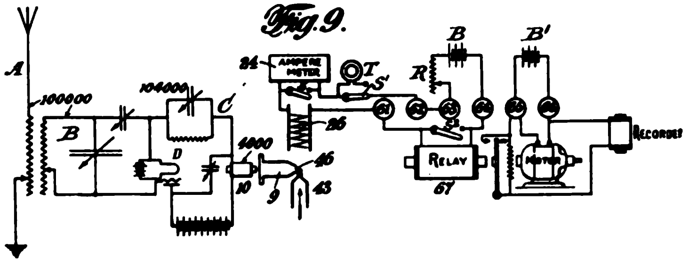


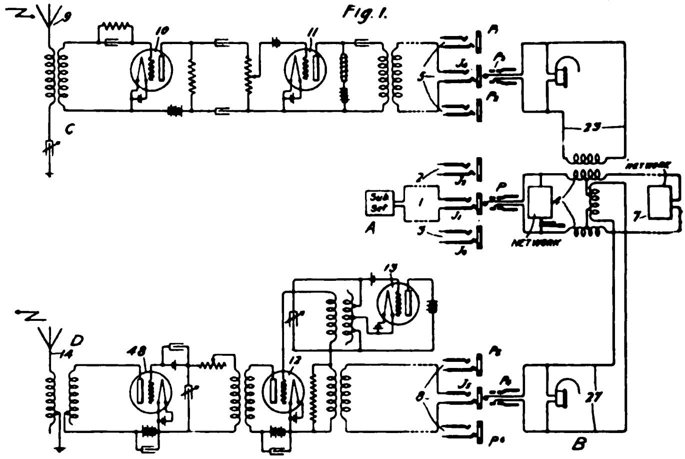
Fig. 9.



Number 1,378,345—Method of and Means For Translating Energy Variations

Method of and Means for Translating Energy Variations whereby a tape record of the incoming radio signal is obtained. A sound sensitive jet of compressed air is varied in accordance with incoming signals and serves to cool an extremely fine wire to vary a condition or quality thereof and actuate a relay in circuit therewith which, in turn, controls the movements of a syphon inker over a progressing tape.

1,378,982—Herbert E. Shreeve, Millburn, New Jersey, filed September 17, 1918, issued May 24, 1921. Assigned to Western Electric Company.

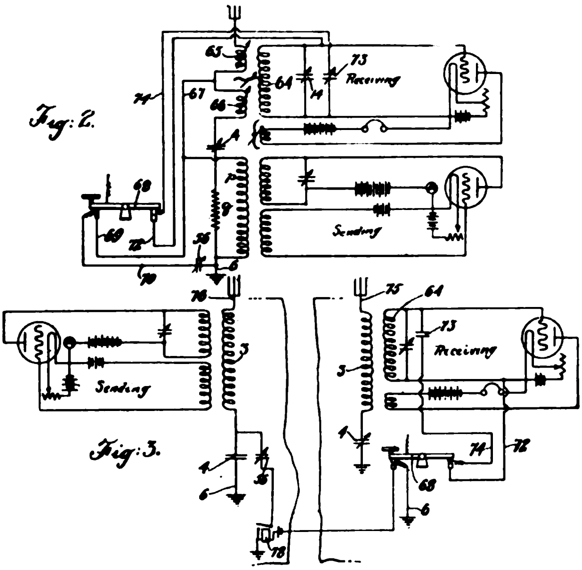


Number 1,378,982—Signaling System

Signaling System for connecting two telephone subscribers by a combined wire and radio link. A central station operator may connect any subscribers' stations simultaneously to the radio transmitting station or the radio receiving station and thus establish telephone communication by wire and radio.

1,379,144—Paul Ware, New York, N. Y., filed February 8, 1918, issued May 24, 1921. Assigned to Ware Radio, Inc.

Cut-in System of Radiotelegraphy which enables the receiving operator to break in on the transmitting operator at any portion of the transmission.



Number 1,379,144—Cut-in System of Radiotelegraphy

1,379,166—Theodore Willard Case, Scipio, New York, filed January 22, 1918, issued May 24, 1921.

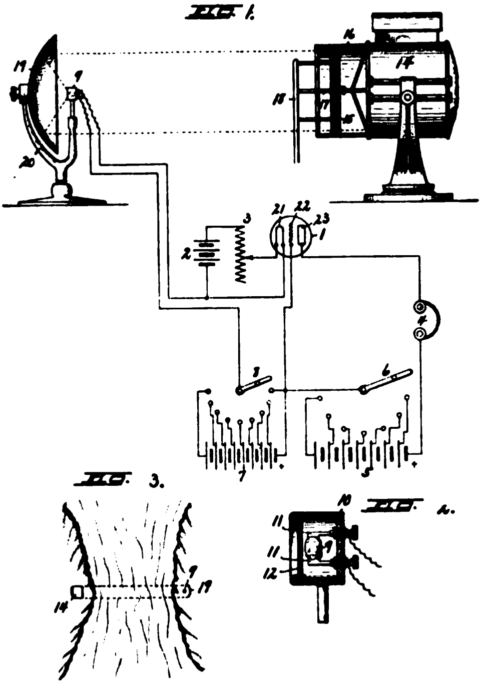
Radiant Energy Signaling System for transmitting by light rays.

1,379,167—Theodore Willard Case, Scipio, New York, filed February 20, 1918, issued May 24, 1921.

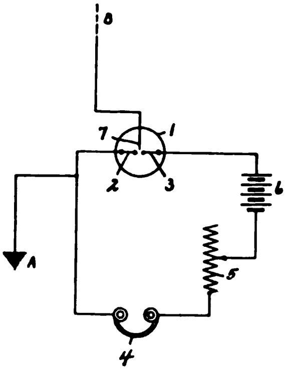
Wireless (Radio) Receiver involving a bulb 1 containing a pair of spaced electrodes 2 and 3 connected in a local circuit 4, 5, and 6. The bulb contains a gas of low dielectric constant and is arranged in an antenna-ground circuit with control member 7, whereby the received oscillations vary the conductivity of the gaseous space and thereby effect variations in the frequency of pulsations of the local circuit.

1,379,184—Louis Alan Hazeltine, Hoboken, New Jersey, filed November 1, 1917, issued May 24, 1921. Assigned to Ware Radio, Inc.

Shielding Radio Apparatus to eliminate the disturbing effects on the tuning caused by movements of the human body, or of other conducting or insulating bodies in the immediate vicinity of the radio apparatus.



NUMBER 1,379,166—Radiant Energy Signaling System



NUMBER 1,379,167—Wireless (Radio) Receiver

1,379,262—Stanton C. Hooper and George H. Clark, Washington, District of Columbia, filed September 16, 1919, issued May 24, 1921.

Fig:4.

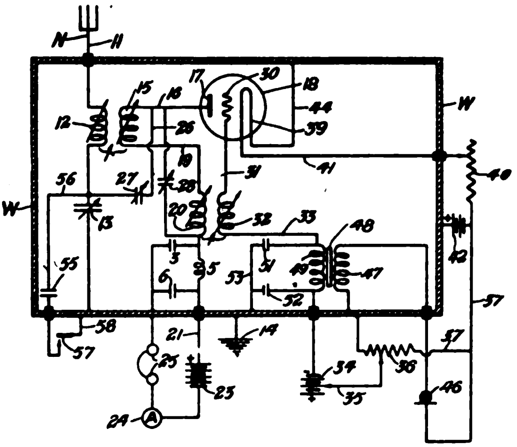


Fig:1.

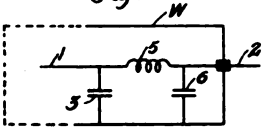


Fig:2.

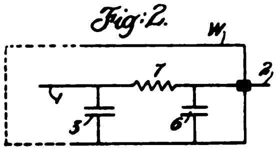
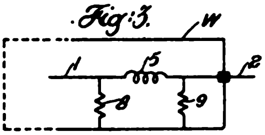


Fig:3.



Number 1,379,184—Shielding Radio Apparatus

Radio Receiving Antenna comprising a plurality of antennas located at approximately equal distances apart on a line bearing in the direction of the distant transmitting station. Each antenna includes a tuning capacity and inductance for bringing the antenna to resonance with the incoming wave length. The several antennas are conductively connected at their extremities and the increments of energy received by each integrated in a radio receiving apparatus.

1,379,541—James Erskine-Murray and James Robinson, Biggin Hill, England, filed October 29, 1910, issued May 24, 1921.

Electromagnetic Wave Navigational Arrangement wherein bearings are determined by noting the interval between the reception of a distinctive signal periodically propagated from the transmitting station in a definite direction and the reception

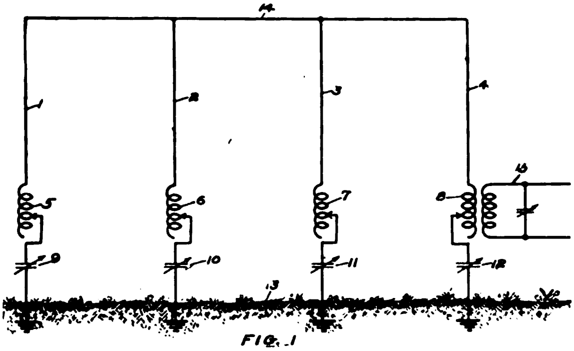


FIG. 1

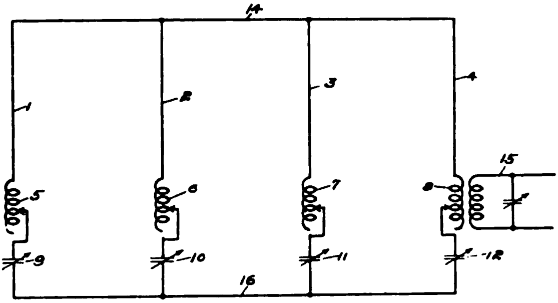
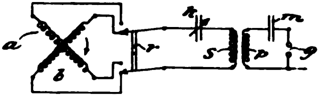
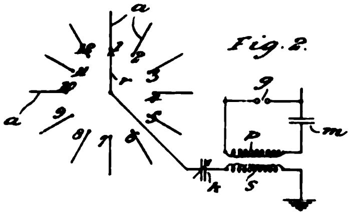


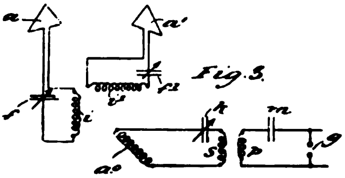
FIG. 2

Number 1,379,262—Radio Receiving Antenna

Fig. 1.

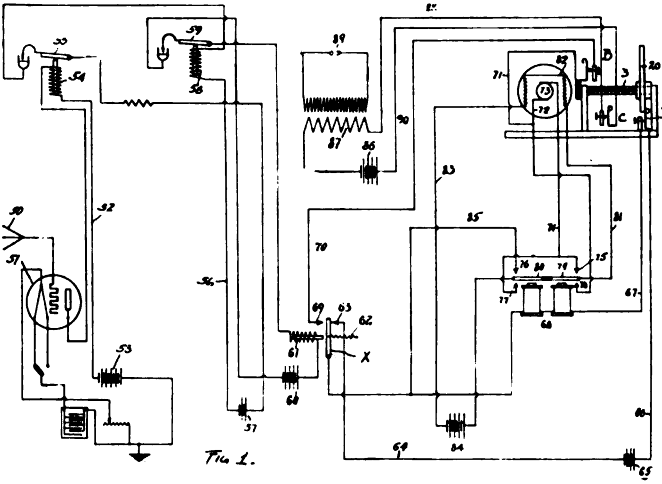






Number 1,379,541—Electromagnetic Wave Navigational Arrangement of a pair of successive signals of equal intensity in a series of signals propagated from the transmitting station in pairs of quickly succeeding individual signals at small equal time intervals, the individual signals of each pair varying in relative intensity in a given direction with the position of a movable element which controls the emission of signals at the transmitting station.

1,379,589—Henry H. Hyder, Hollywood, California, filed June 5, 1918, issued May 24, 1921.



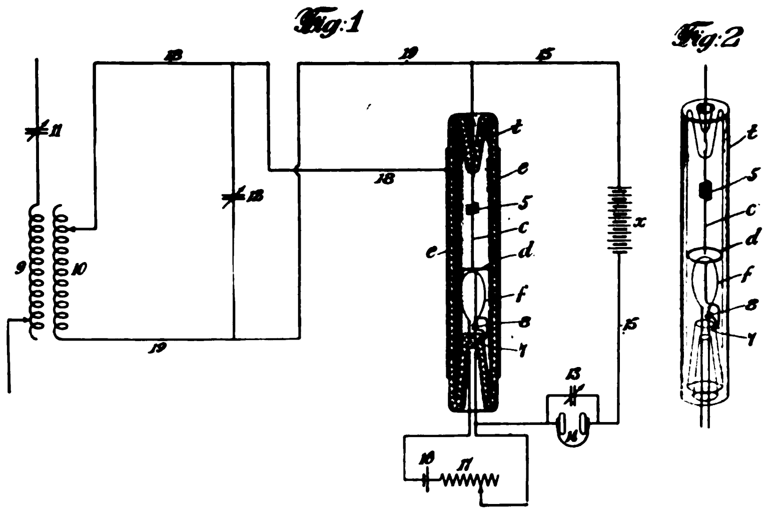
Number 1,379,589—Radio Apparatus

Radio Apparatus for mechanically locking an electrical circuit in open position in connection with the exploding of mines. The device may be operated from a distance by a radio operator knowing the necessary intervals of time for closing and opening the circuit controlling the mechanical lock and operating mechanism for closing the working circuit.

1,379,706—Roy Alexander Weagant, Roselle, New Jersey, filed March 10, 1917, issued May 31, 1921. Assigned to Radio Corporation of America.

Vacuum Valve Detector having an exterior control element. The improvement consists of a guard device *d* in the form of a ring and disposed adjacent to the point where the cath-

Fig:1 Fig:2



Number 1,379,706—Vacuum Valve Detector

ode and anode approach each other and is electrically connected to the cathode. It operates to discharge any charge that occurs or accumulates on the exterior wall of the tube in the vicinity of its location.

1,380,206—Roy Alexander Weagant, Roselle Township, Union County, New Jersey, filed March 10, 1917, issued May 31, 1921. Assigned to Radio Corporation of America.

Vacuum Valve Detector of the external control type. The hot and cold elements are arranged in the tube so that they form points between which the electron flow will be continuous and uninterrupted in the presence of disturbing causes such as static and high potential transmitted impulses.

1,380,663—John Lindgren, Lemont, Illinois, filed May 16, 1918, issued June 7, 1921.

Radio Control Device for synchronizing the movement of an armature located at a distance receiving station with the movement of a commutator circuit closer located at the transmitter.

1,380,872—Roy E. Thompson, New York, N. Y., filed September 24, 1917, issued June 7, 1921.

Radio Communication Transmitter with an exciting cir-

Fig:1

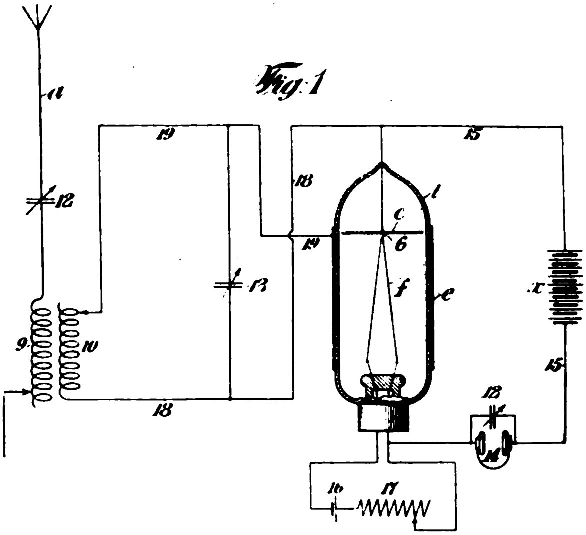


Fig:3

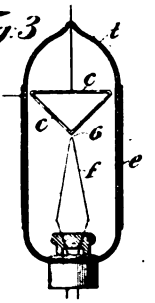
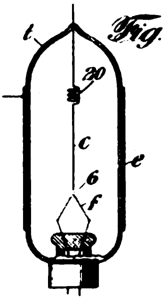
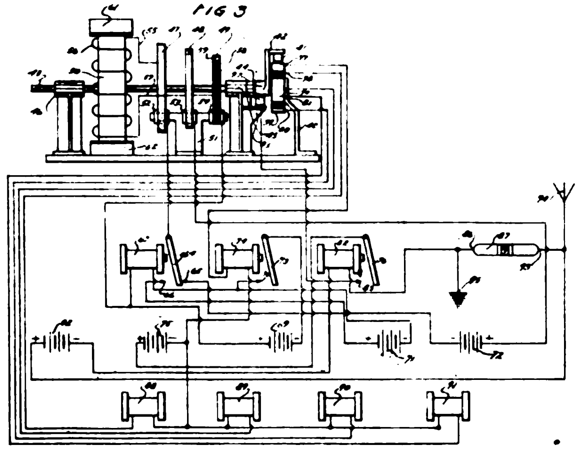


Fig:2



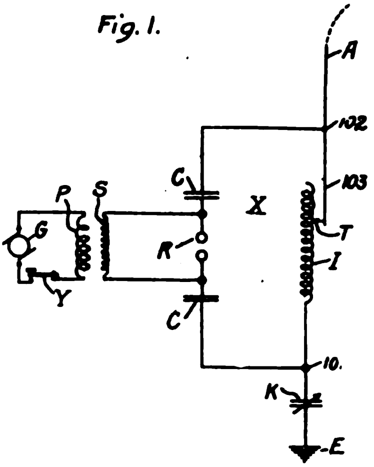
NUMBER 1,380,206—Vacuum Valve Detector

FIG 3



NUMBER 1,380,663—Radio Control Device

Fig. 1.



NUMBER 1,380,872—Radio Communication Transmitter

cuit of non-persistent oscillatory character, and a radiating circuit of a persistently oscillating character. A multiple unit spark gap adjustable from a single control is employed in the set.

1,381,089—Harold H. Beverage, Schenectady, New York, filed April 10, 1920, issued June 7, 1921. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM in which a horizontal receiving antenna is employed. The distributed constants of the antenna are of such values that the waves produced therein will be propagated along its length at substantially the same velocity as that at which the desired signaling waves travel along its length in the ether.

1,381,474—Jakob Kunz, Urbana, Illinois, filed August 24, 1918, issued June 14, 1921. Assigned to Board of Trustees of the University of Illinois.

PHOTO-ELECTRIC CELL, METHOD AND MEANS FOR MAKING THE SAME. The cell may be used as a wave detector and when so employed the cell is excited by the light source *L*, as shown in Figure 4, so that electrons pass from the film electrode to the screen electrode within the cell. The incoming waves entering by way of the antenna 31 are rectified by the cell and give an indication at the indicator 25 then passing to ground at 32.

Fig. 1

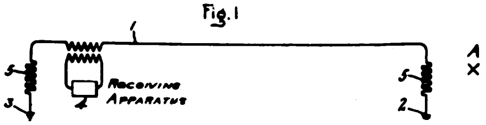


Fig. 2

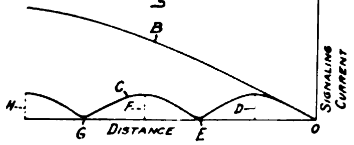


Fig. 3

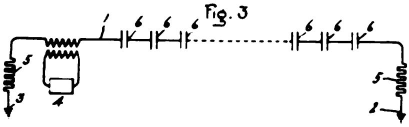
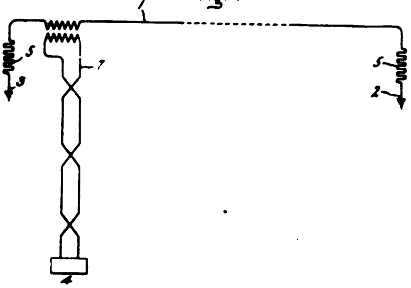
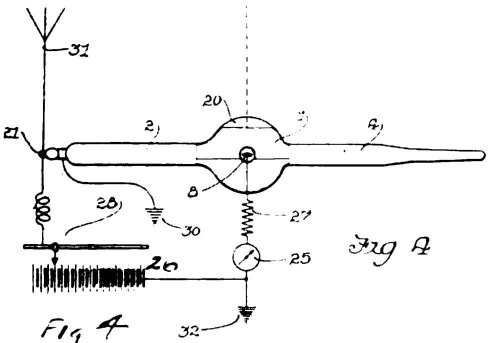


Fig. 4



NUMBER 1,381,089—Radio Receiving System



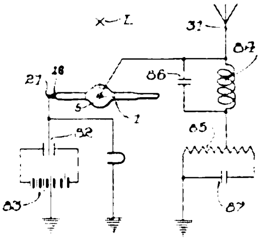
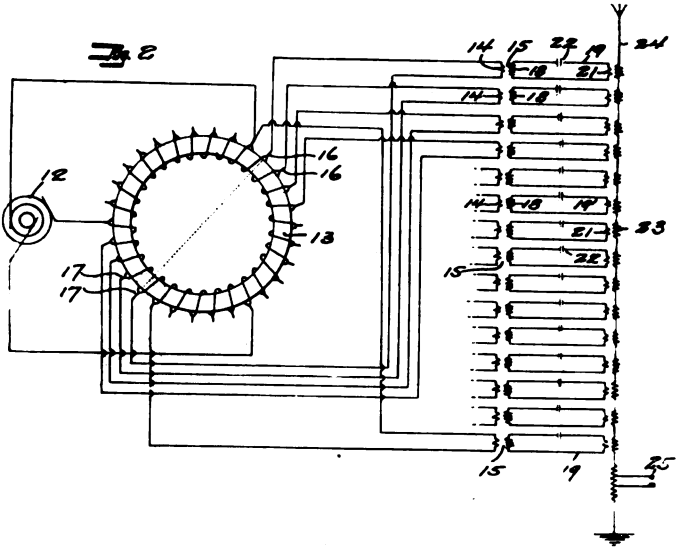


Fig 6

NUMBER 1,381,474—Photo-Electric Cell, Method and Means for Making the Same

The source of current 26 may be omitted. The current operating on the indicator 25 may be amplified by a vacuum tube or other relay device.

1,381,626—Leonard F. Fuller, San Francisco, California, filed January 19, 1918, issued June 14, 1921. Assigned to Federal Telegraph Company.



NUMBER 1,381,626—Process and Apparatus for Producing Radio Frequent Current

PROCESS AND APPARATUS FOR PRODUCING RADIO FREQUENT CURRENT in which the impulses are caused to follow each other in phase by a phase-multiplying transformer. Polyphase current, preferably three phase, is fed into the phase-multiplying transformer and taps on the phase-multiplying transformer winding are connected to the respective impulse transformers, the taps for each impulse transformer being located at diametrically opposite points. The secondaries of each impulse transformer are included in separate oscillating circuits, each associated with the radiating circuit.

1,381,692—Cesare Bardeloni, Rome, Italy, filed April 12, 1919, issued June 14, 1921.

Fig. 1.

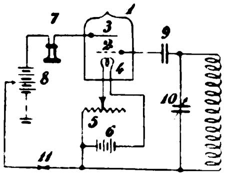


Fig. 2.

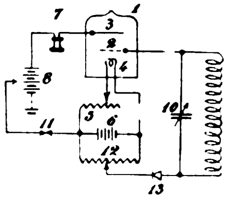


Fig. 3.

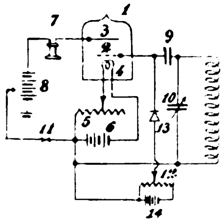


Fig. 4.

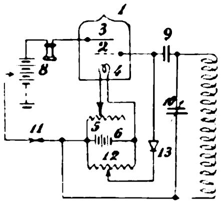


Fig. 5.

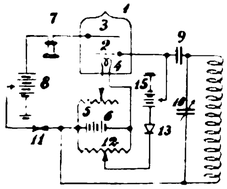
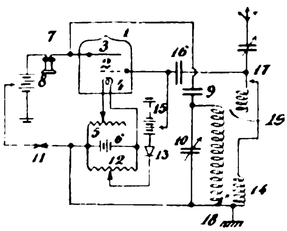


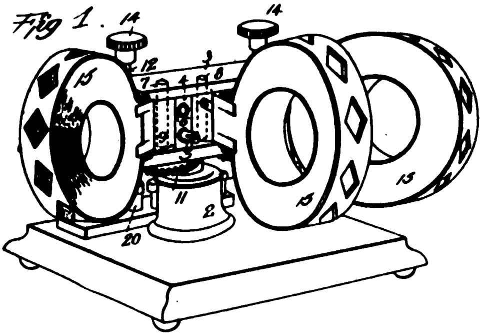
Fig. 6.



Number 1,381,692—Device for Receiving Radio Telegraphic and Radio Telephonic Signals

Device for Receiving Radio Telegraphic and Radio Telephonic Signals, comprising a circuit including an oscillating vacuum tube with the addition of a rectifying device inserted across the filament and grid thru a potentiometer. The action of the rectifying contact, owing to its insertion with respect to the oscillating circuit with which it is connected in parallel and with respect to the electrode 2 of the ionized gas receiver, may be assumed to be a double one: 1st that of actual amplification of the signals by the increase of positive charges which flow to the electrode 2 during the oscillations set up in the oscillating circuit; 2nd that of unification of the ionized medium about the electrode 2, so as to neutralize, by means of negative charges reaching to the electrode thru the contact, the excess of free positive charges due to the direct influence of the electrode 2, which latter thus follows only the charge variations which the aforesaid oscillating circuit impresses thereon.

1,365,170—Robert Fellons Gowen, New York, N. Y., filed August 20, 1919, issued January 11, 1921. Assigned to De Forest Radio Telephone and Telegraph Company.



NUMBER 1,365,170—Inductance Coil Mounting

1,366,627—Ernst F. W. Alexanderson and Samuel P. Nixdorff, Schenectady, New York, filed December 8. 1918, issued January 25, 1921. Assigned to General Electric Company.

HIGH (RADIO) FREQUENCY ALTERNATOR having an exciting field made up of a plurality of semicircular coils embracing the periphery of each half of the machine frame.

1,367,734—Austen M. Curtis, Brooklyn, New York, filed August 16, 1917, issued February 8, 1921. Assigned to Western Electric Company.

CONSTRUCTION OF REACTANCE COILS in which the conductor is wound on a structure composed of two semicylindrical forms. The construction is such that the inductance has no external field.

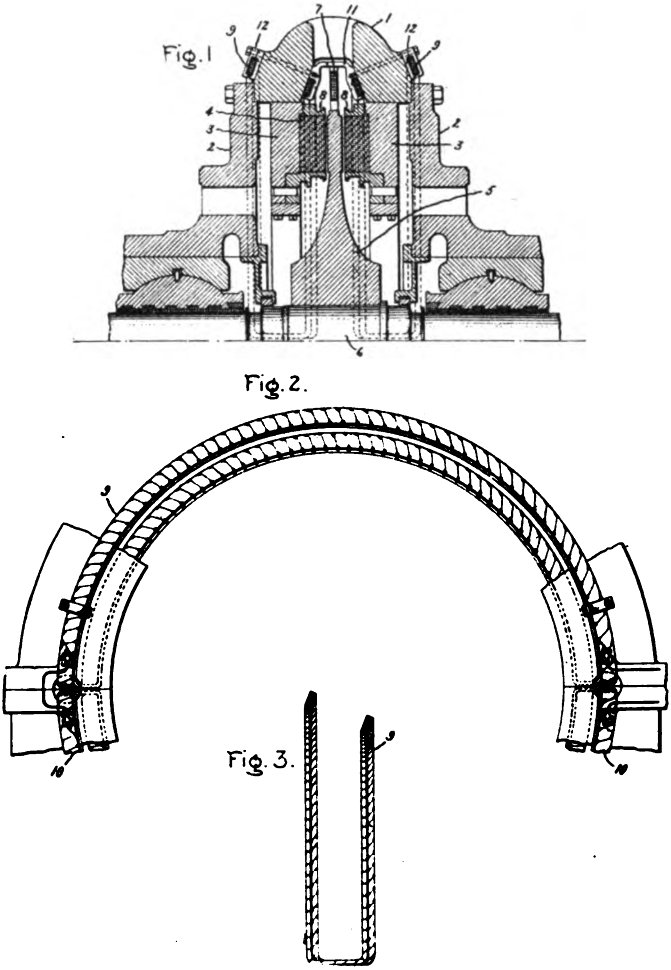
1,369,601—Ernst F. W. Alexanderson, Schenectady, New York, filed November 4, 1918, issued February 22, 1921. Assigned to General Electric Company.

HIGH (RADIO) FREQUENCY ALTERNATOR having an inductor

Fig. 1

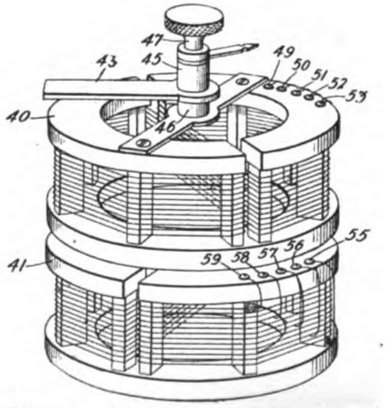
Fig. 2.

Fig. 3.



NUMBER 1,366,627—High (Radio) Frequency Alternator

Fig. 3



NUMBER 1,367,734—Construction of Reactance Coils

Fig. 1.

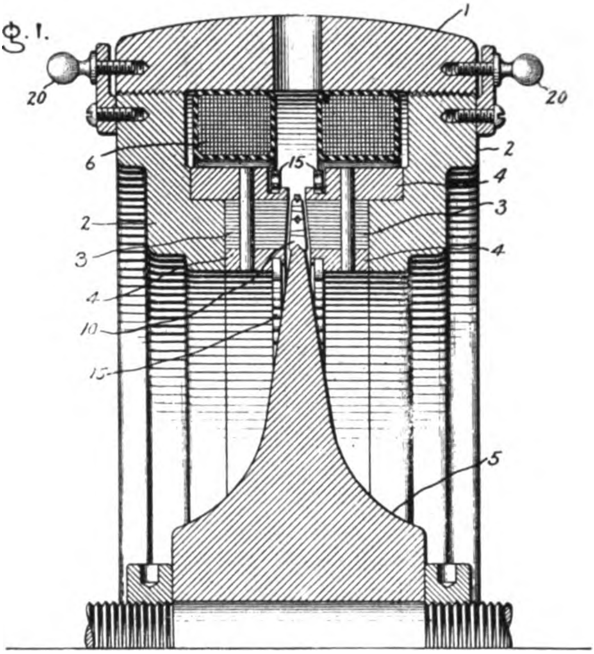


Fig. 2.

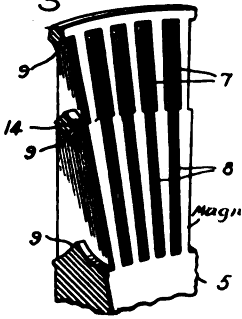


Fig. 3.

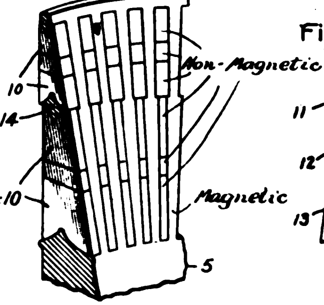


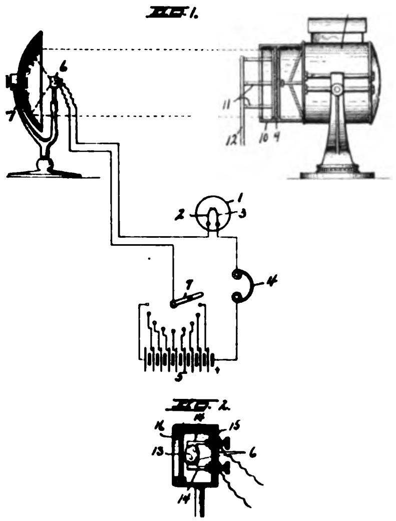
Fig. 4

NUMBER 1,369,601—High (Radio) Frequency Alternator

formed with two circumferential rows of radial slots and non-magnetic filler disposed in the slots.

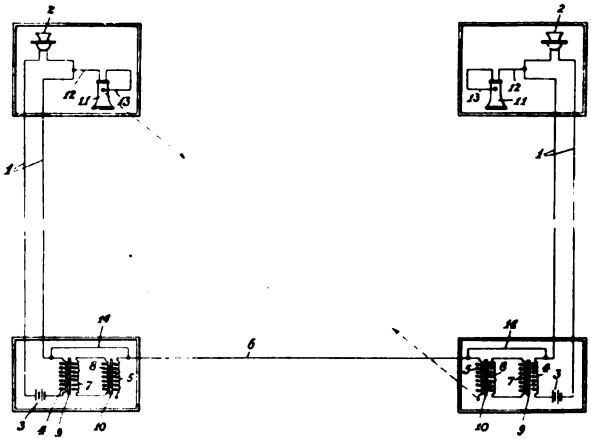
1,369,781—Theodore Willard Case, Scipio, New York, filed February 20, 1918, issued March 1, 1921.

SIGNALING SYSTEM for transmitting by light rays.



NUMBER 1,369,781—Signaling System

1,370,333—William W. Macfarlane, Elkins Park, Pennsylvania, filed May 15, 1919, issued March 1, 1921.



NUMBER 1,370,333—System of Communication

SYSTEM OF COMMUNICATION at audio frequency in which the two telephone stations are connected by a single conductor and the other terminals of the respective sets grounded.

FURTHER DISCUSSION ON

"ON THE POULSEN ARC IN COUPLED CIRCUITS"*

BY

P. O. PEDERSEN

P. O. Pedersen (by letter): Mr. L. F. Fuller is of the opinion that I have not used "tuned" fields in my experiments on the Poulsen arc in coupled circuits. Since I myself am responsible for the original discovery of *"The existence, in every particular case, of a certain field intensity, H°, giving maximum efficiency and greatest constancy"*[1] and *"The dependence of H° on wave length, gas density, supply current, and radio frequency resistance,"*[2] I really think I would have been altogether too negligent and dull had I not, in every single case, brought the strength of the magnetic field to its most suitable value. And, of course, the field actually was properly chosen in every case.

Some other points in Mr. Fuller's discussion might also warrant comment, but as he agrees with my main conclusion, I do not think there is any necessity for carrying the discussion further.

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* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 9, page 242, 1921.

[1] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, page 309, 1917.

[2] Italicized in the original.

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 9 OCTOBER, 1921 Number 5

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NAVAL RADIO TUBE TRANSMITTERS*

By

T. Johnson, Jr.

(Formerly Radio Aid, Navy Department, Washington, D.C.)

Introduction

During recent years the development of the vacuum tube and the vacuum tube transmitter has received a great deal of consideration from radio engineers, but there is doubtless no field in this country in which this type of apparatus has received the application and standardization that it has in the Naval service.

This is quite logical, for the Navy Department largely represented in this respect by Commander S. C. Hooper, in charge of the Radio Division, Bureau of Engineering, has been a leading factor in urging the more universal use of continuous wave transmission. In attempting the use of continuous waves in the case of low power, short wave installations, it has been proven that the vacuum tube transmitter held forth the greatest promise of success. The high cost of maintenance due to the prices of transmitting tubes has been a matter of some concern, but in spite of this the Navy Department has pursued the development of the vacuum tube transmitter, realizing that by furthering the use of this type of apparatus, the price of tubes would be materially reduced. In this alone the Department has rendered a very great service to the entire radio world.

In pursuing the continued development of the vacuum tube transmitter the Department has been greatly influenced by the possible accomplishment demonstrated in the aircraft and submarine chaser equipment developed for use in the war. In the use of this apparatus, the value of the vacuum tube radio telephone for military purposes was demonstrated beyond the question of a doubt.

A certain amount of weight has been attached to a large number of comparative tests conducted under various experi-

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*Received by the Editor, December 18, 1920. Presented before The Institute of Radio Engineers, New York, January 5, 1921. This paper was arranged for and in the main prepared prior to September 1, 1920

mental and service conditions. One of the most interesting tests of this kind was conducted in October, 1919, from the Radio Test Shop, Navy Yard, Washington, D. C., using standard Navy transmitters, spark, arc, and tube of approximately 2 kilowatt input ratings. An antenna current of 8.0 amperes was maintained thruout the test in the Navy Yard antenna (illustrated in Figure 31). All of the transmission was conducted on a wave length of 1,900 meters. The schedule covered periods thruout day and night for one week. Reception was conducted at Navy Yard, Norfolk, Virginia, at Navy Yard, Philadelphia, Pennsylvania, at Naval Radio Station, Otter Cliffs, Bar Harbor, Maine, and at the Bureau of Standards, Washington, D. C.

The results obtained are tabulated in Figure 1. No claim is made for the results other than that they represent the average comparative audibility at different stations of three methods of transmission, each type of transmitter delivering the same current to the same antenna, with receiving conditions, during a given schedule remaining constant, except for the change in regenerative coupling during spark schedules. It is not claimed that the results obtained are conclusive in indicating the merits of the three types of transmission. They should be interpreted merely as a record of comparative audibilities obtained during a particular series of schedules, and as tabulated are an average of approximately 750 independent audibility measurements, taken during day and night over a period of one week, the reception being conducted by Naval personnel using standard apparatus. The results are therefore of great value in indicating, not what may be accomplished under specially arranged experimental conditions, but that which may be accomplished by an operating service under average conditions.

In order to permit a simple review of the results, the audibilities obtained at the receiving stations have been converted into factors representing comparative audibility of signals to the audibility of signals received by detection only, the actual audibility of the spark signals recorded under these conditions being assumed as unity. The factors representing the ratio of audibility of any other signal to spark with detection only, have been carefully checked for each station and those which were obviously low or high have been eliminated. Approximately 15 per cent of the total number of readings have been thus eliminated. The remaining factors were averaged for each station, and these averages are tabulated in Figure 1. The three factors representing the average ratio of audibility of any signal

Schedule	Transmission Washington, D.C. 1,900 Meters	Reception (Vacuum Tube)	Ratio of Signal Audibility to Schedule Number 1 Signal Audibility			
			Norfolk, Virginia	Philadelphia, Pennsylvania	Bar Harbor, Maine	Average
1	Spark	Detection only	1	1	1	1
2	Spark	Detection and Regeneration	4.7	3.1	2.8	3.5
3	Continuous Wave Buzzer Modulated	Detection only	5.7	6.7	2.4	12
4	Spark	Detection, Regeneration and Oscillation	46	18	9	24
5	Arc		179	65	72	105
6	Tube		435	63	118	205
Distance from Transmitter		Nautical Miles	103	124	620	262
		Kilometers	191	230	1150	529

FIGURE 1

at the three receiving stations were again averaged, giving resultant figures tabulated in the column marked "Average."

The basic requirements of the Naval service impose upon vacuum tube transmitting equipment a large number of rather severe conditions which must be carefully considered. In the majority of cases provision must be made so that any one of a number of wave lengths or power outputs may be adjusted to instantly. Selection of telephone, continuous wave telegraph, or interrupted continuous wave telegraph methods of communication must be possible without the slightest delay regardless of the wave length and power being used. The transmitter must often be operated in connection with some more or less complicated control system. Arrangements must be made so that in the event of failure of units under severe wear, spare parts may be substituted immediately. The space available for installation is usually very limited in one or more dimensions.

The apparatus must be capable of the widest range of operating possibilities and yet must be simple to operate, rugged in the extreme, absolutely reliable, and must embody the degree of general standardization which permits of a simple and effective maintenance service. It is indeed a somewhat difficult combination of conflicting demands which the tube transmitter meets in its adaptation to the Naval service.

The problem of maintenance has forced an early standardization of tubes and tube equipment. Spare tubes and other spare parts must be made available at a large number of very widely located Naval establishments, and a multiplicity of spares is a source of great expense and more occasional error in distribution. This fact has placed several necessary restrictions on development and has forced the Department to standardize upon tubes of certain ratings and upon strictly interchangeable types of tube under each rating. Results of not following this policy in the case of the 5-watt tube have demonstrated very emphatically the necessity of adhering to it in the future. Whenever a tube of a certain rating is developed which is of sufficient superiority to the standard tube or tubes, altho not interchangeable with them, it must completely supersede them.

In a great deal of standardization, it has been necessary to await demonstration that there could be furnished in quantity uniform products in the form of tubes, power equipment and other accessories new to the electrical art and heretofore laboratory devices only. This procedure is of extreme importance in a military organization where, in order to be useful in emergencies, apparatus must be readily adapted to production in large quantities within a very short time.

In brief, the development of vacuum tube transmitters for the Naval service has been based on a policy involving very serious considerations and therefore the standard apparatus resulting may well be viewed as worthy of unusual attention.

STANDARD EQUIPMENT

In view of the rapid progress in the art and the time required to develop and produce in quantity apparatus of this kind, it is not possible that any standard apparatus herein described embodies the results of the most recent developments. Further, it may be noted that some of the apparatus, such as power equipment, reveals a marked difference in fundamental design, from one set to another. This is quite natural as these equipments were not developed simultaneously; and, for the most part, these differences mark the successive stages of development in this type of apparatus.

The significance of the ratings of these equipments should also be made very clear. It has been Naval practice to rate tube transmitters in power output, the rating to be the sum of the power output ratings of the oscillator tubes. In every case, due to various losses, the actual power output of the set is somewhat lower than the rated output.

As regards transmitting range, the available material in the form of results of carefully conducted tests is so very meager that for the most part reference to range is omitted here. Wherever a range rating is stated, it is only presented as the best information obtainable on the subject at the present time and is qualified by the assumption of daylight transmission in a temperate latitude under average weather conditions to a station of similar nature equipped with a standard vacuum tube receiver with two stages of audio frequency amplification, an audibility of 200 being required.

It will be noted that in all the transmitters now standard, there is used one of two fundamental circuits: (1) that in which plate and grid circuits are inductively coupled to the antenna circuit, or (2) the Colpitt's circuit, in which the grid receives its excitation from a condenser in the antenna circuit. In either of these cases, the emitted wave length is determined by the constants of the antenna circuit and many disadvantages arise because of this fact. However, there are several fundamental reasons which have been considered justification for the use of either of these circuits rather than some system in which the emitted wave length is independent of the antenna circuit constants. The sets designed have each required operation on quite a number of wave lengths, they have all been of comparatively low output, and it has been required that their controls be of the simplest nature. Because of the uniformity of Naval vessels of any class, it has been possible to establish a relatively small range of antenna characteristics thruout which it is required in each case to operate.

In so doing it has been necessary to make a careful investigation, preliminary to the transmitter design, of the antenna characteristics in the case of all stations and vessels to be equipped with tube transmitters. A large number of measurements have been made with a piece of apparatus essentially the same as that used in the aircraft work described by the author in a previous paper,[1] but now more standardized in design and manufactured in quantity. It is a radio test set, designed and manufactured by the General Electric Company, the schematic circuit diagram of which is illustrated in Figure 2. It consists of three essential parts, an oscillator, an antenna unit, and a dynamotor, power being supplied from a 12-volt storage battery.

The oscillator, illustrated in Figure 3, is 13 inches (33 cm.) wide by 13 inches (33 cm.) high, by 14 inches (35.6 cm.) deep, and weighs 24 pounds (10.8 kilograms). These dimensions include a cover for the panel face, the cover being 2 inches (5.1 cm.) deep and mounted on slip hinges. The oscillator has a wave length range of 150 to 4,500 meters and employs a single 50-watt tube, Type CG 1144, the filament of which is supplied with energy from the 12-volt battery which supplies the dynamotor. On the face of the bakelite panel are mounted filament ammeter and rheostat control, dynamotor starting switch, grid and plate coil switch, switch for placing an external condenser in the oscillating circuit, variable condenser control and dial, jack for plate coupling coil, and necessary binding posts. On the reverse side of the panel are mounted the tube, variable condenser, coil system, and necessary accessories. A spare tube is mounted within the case.

The antenna unit, illustrated in Figure 4, is 13 inches (33 cm.) wide by 13 inches (33 cm.) high, by 14 inches (35.6 cm.) deep,

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[1] See T. Johnson, Jr., "Naval Aircraft Radio," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1920, volume 8, number 1, page 16.

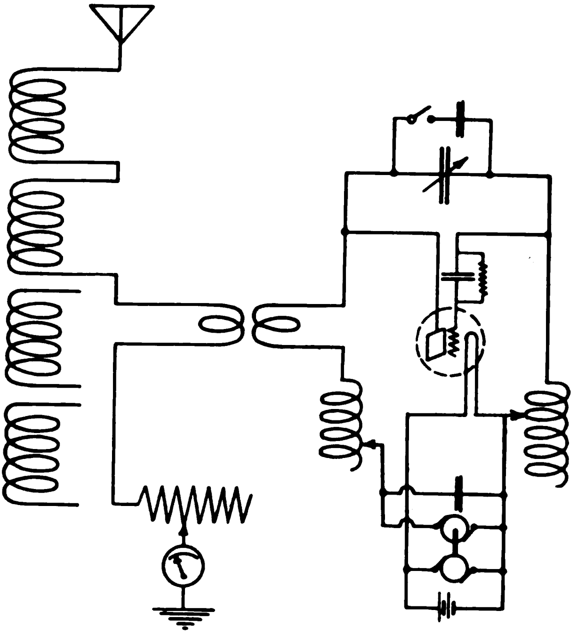

FIGURE 2

and weighs 22 pounds (9.9 kilograms). This unit provides a series of loading coils for increasing the wave length of the antenna circuit, a resistance in three sections variable from 0.1 ohm to 111.0 ohms, and a spring-mounted 0-125 milliampere hot wire meter. A fixed bakelite panel provides mounting for the above mentioned devices. Controls on the face of this panel consist of a switch for insertion of loading inductance in 18 steps and for open circuiting coils when not in use, and three knobs for the insertion of the various resistance values. For effecting variable coupling between the plate coil and antenna circuit, coils adjustable in position are provided on the antenna unit.

The dynamotor, is 8 inches (20.3 cm.) long by 6 inches (15.2 cm.) wide by 6.5 inches (16.5 cm.) high, and weighs 11 pounds (5 kilograms). In normal operation it draws 16.5 amperes from the 12-volt storage battery and supplies 80 to 140 milliamperes at 350 volts to the plate circuit of the tube. In addition to its value for measuring antenna constants, the above described equipment is adapted to measurement of various units and circuits.

The method of measuring antenna constants is the same as that used in the aircraft work. In the results of the measurements the term *fundamental capacitance* is now applied to that capacitance which, used in conjunction with the antenna inductance, will resonate at the natural wave length of the antenna. The *equivalent capacitance* at any loaded wave length

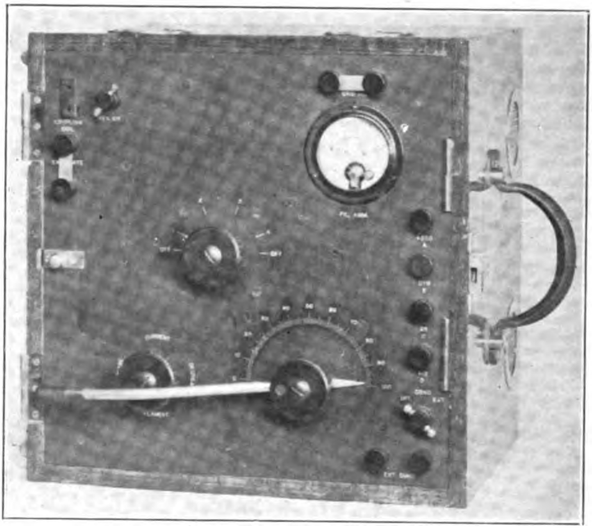

FIGURE 3A

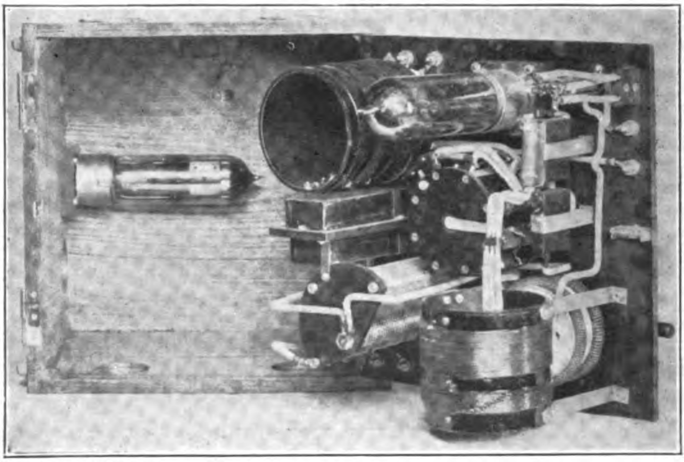

FIGURE 3B

is still defined as that capacitance which, if used with an inductance equal to the loading inductance, will resonate at the same wave length as if loading inductance were applied to the antenna.

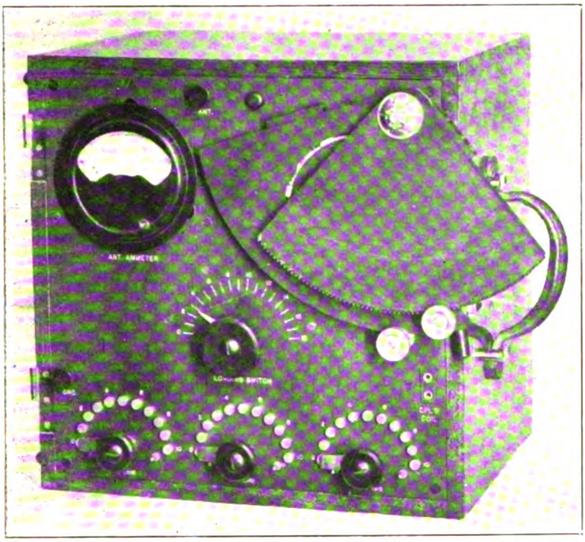

FIGURE 4A

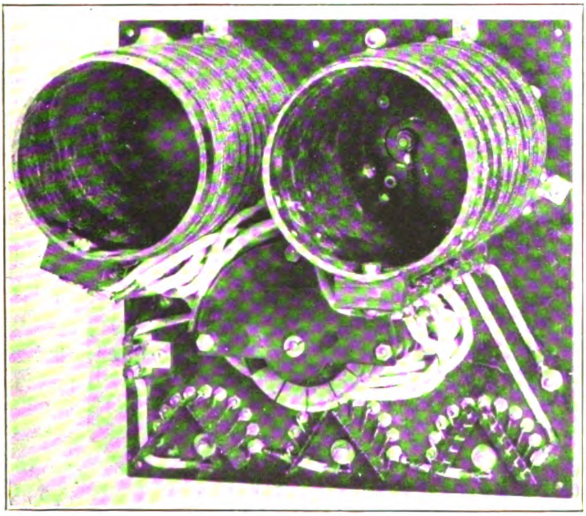

FIGURE 4B

TUBES

The tubes used in the present Naval transmitters are those used in the aircraft work and have been quite fully described in a previous paper.[2] However, for convenience of reference a brief tabulation is given in Figure 5. The two 5-watt tubes, now standard, are illustrated in Figure 6, the 50-watt tube in Figure 7, and the 250-watt tube in Figure 8. The latter shows the standard method of crating the 250-watt tube for shipment.

As previously stated, the standardization of tubes has been based to a large extent upon the availability in quantity of a satisfactorily uniform and rugged product. The design of most

Navy Type Number		CW 931	CG 1162	CG 1144	CG 916
Signal Corps Designation		VT-2	VT-14	VT-18	VT-10
Manufacturer		Western Electric Co.	General Electric Company		
Manufacturer's Designation		E	T	U	P
Rated Values	Watts Output	5	5	50	250
	Filament Volts	7.0	7.5	10.0	20.0
	Filament Amperes	1.35	1.75	6.5	3.85
	Plate Volts	350	350	1000	2000
	Plate Amperes	0.040	0.040	0.150	0.250
Life*	Filament Supply Rated Voltage A. C.		110 hours	250 hours	200 hours
Life Test	Plate Voltage		350	1000	2000
	Plate Watts		17.5	100	250
Length over-all		4.25 inches 10.8 cm.	4.31 inches 10.92 cm.	7.5 inches 19.0 cm.	14.25 inches 39.15 cm.
Diameter, Maximum		2.28 inches 5.78 cm.	1.75 inches 4.44 cm.	2.0 inches 5.08 cm.	5.0 inches 12.7 cm.
Weight		1.87 ounces 53 grams	1.86 ounces 52.6 grams	5.88 ounces 166.5 grams	23.36 ounces 660 grams

* With filament supply at rated current, the life in each case is approximately one-third that tabulated above.

FIGURE 5

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[2] See T. Johnson, Jr., "Naval Aircraft Radio," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1920, volume 8, number 1, page 42.

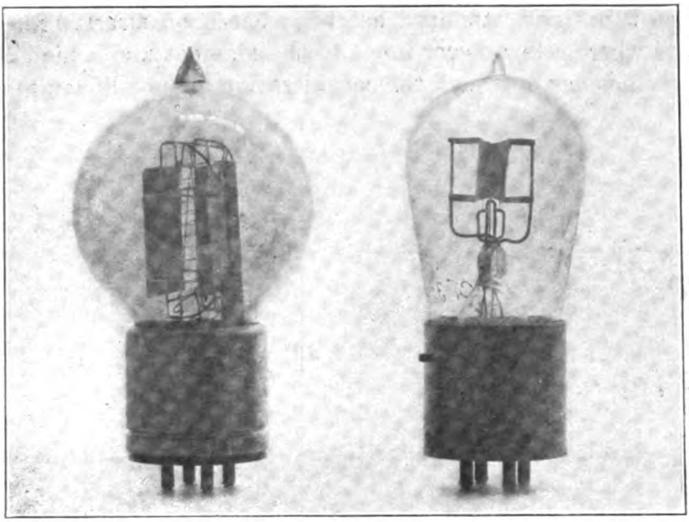

FIGURE 6

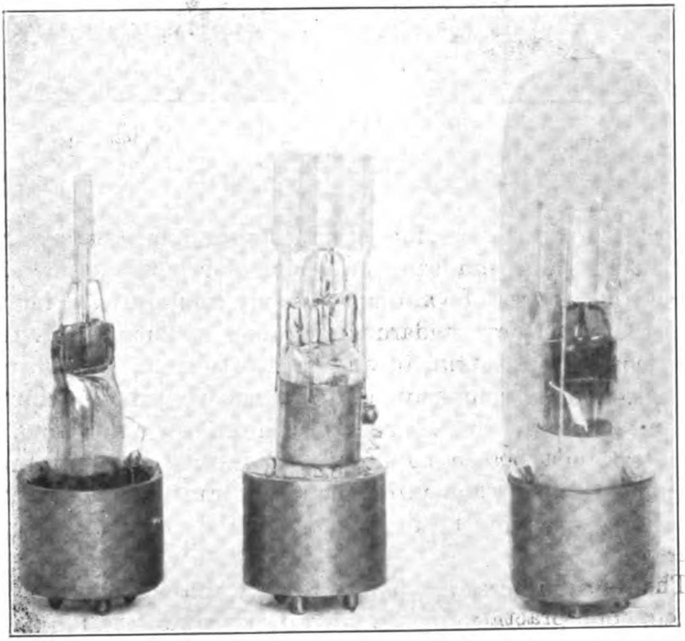

FIGURE 7

of the tubes now standard has been based on aircraft requirements where a low power input to the filament and a high operating efficiency outweigh the consideration of tube life and many other factors which are of great importance in other than aircraft work. This fact, and the promising development now being carried on in tubes of various filament compositions, indicates that the tubes now standard may soon be superseded. It has been considered essential to adhere to tubes of specific power ratings, and to completely interchangeable tubes, electrically and mechanically, in each rating. Thus a new non-interchangeable tube must possess sufficient superiority over the present standard to justify the entire change in transmitting equipment which the changing of the standard tube characteristics may necessitate.

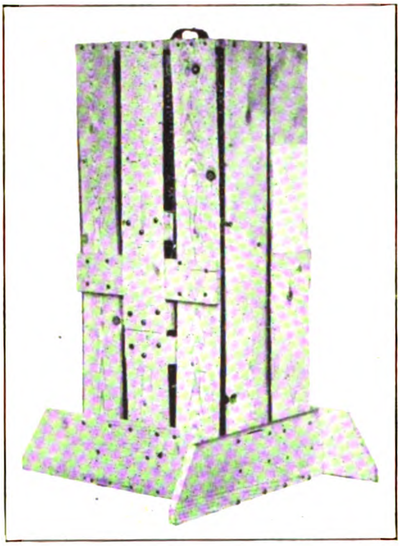

FIGURE 8A

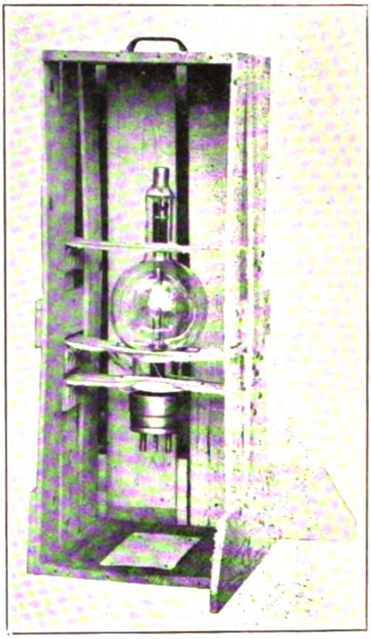

FIGURE 8B

The most interesting points recently brought out in transmitting tube practice in the Naval service are (a) the lighting of filaments from an alternating current supply, and (b) the supplying of energy to the filaments at a constant voltage.

Both of these operating practices improve the filament life very appreciably. For instance, operated in a standard transmitter under normal conditions, a 5-watt tube, Type CG 1162, has an average life of 30 hours when the filament is operated from a direct current source at constant rated current. The average antenna current obtainable from the apparatus just prior to tube burnout under these conditions shows a drop of 7.5 percent from the initial antenna current, no adjustments whatsoever being made on the apparatus during the test. Operating under identical conditions, but from an alternating current source at constant rated filament voltage, the tube has an average life of 110 hours, the antenna current dropping but 4.5 percent from start to end of test, no adjustment being made thruout.

An additional advantage of constant filament voltage operation is that tubes of widely different filament currents may be operated satisfactorily in parallel, provided other conditions are properly fulfilled. Thus there is removed at least one fundamental difficulty in operating in parallel tubes of different filament composition.

TRANSMITTING EQUIPMENTS

Altho no longer considered strictly standard in apparatus of its class, reference should be made at this point to the submarine chaser radio telephone equipment, the combined transmitter and receiver developed and manufactured by the Western Electric Company, and which rendered such valuable service during the war. This set was developed and produced in quantity in a remarkably short time under the stress of war conditions and marks an extremely important stage in the application of vacuum tube transmitters to the naval service; indeed, as regards such application in quantity, it holds acknowledged place as pioneer.

This equipment is intended for short range communication between submarine chasers and other small vessels, and is arranged for telephone communication only. It is designed for operation on any one of five wave lengths from 200 to 600 meters, using an antenna of the following characteristics, and having an antenna input of approximately 5 watts:

Fundamental Wave Length—190 meters.

Fundamental Capacitance—600 micromicrofarads.

The transmitter uses one 5-watt tube as an oscillator and one 5-watt tube as a modulator, and has a dependable telephone working range of 10 nautical miles (18.5 kilometers).

The schematic circuit of the entire transmitting and receiving equipment is illustrated in Figure 9. The grid circuit of the oscillator tube receives its excitation from an antenna circuit condenser, thus necessitating, at each change of wave length, the adjustment of the capacitance of this condenser so as to give the proper wave length in conjunction with other antenna circuit adjustments and still insure the correct grid excitation.

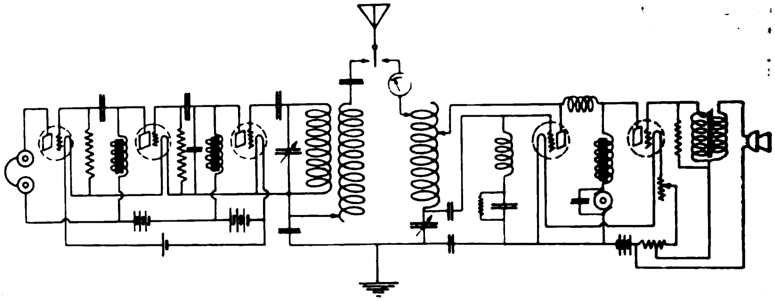

FIGURE 9

The main equipment consists essentially of a transmitter-receiver cabinet, a receiving amplifier, a switchboard and a dynamotor unit. The transmitter-receiver cabinet, illustrated in Figure 10, is 24.75 inches (65.4 cm.) wide by 18.5 inches (47 cm.) high by 6.63 inches (16.8 cm.) deep, and weighs 56 pounds (25.2 kilograms.) On the front of the cabinet are mounted antenna, plate and filament ammeters, and manual controls for send-receive switch, filament rheostat, receiver condensers, receiver inductance, and amplifier switch. A protected auxiliary panel, at the left, contains the adjustable controls for the antenna inductance and the input capacitance. After these adjustments are properly made, a cover is screwed over the auxiliary panel to protect the adjustments and to prevent accidental contact with the radio frequency high voltage circuit.

The receiving amplifier, shown in Figure 11, is a cabinet 19.5 inches (49.5 cm.) wide by 11 inches (28 cm.) high, by 6.13 inches (15.6 cm.) deep, and weighs 28.5 pounds (12.5 kilograms). It contains a two-stage amplifier with receiving tubes and a one-stage amplifier with a 5-watt transmitting tube. These amplifiers are used to amplify the voice current sufficiently to operate a loud speaking telephone.

The switchboard shown in Figure 12 is 11.5 inches (29.2 cm.) wide by 12.75 inches (32.4 cm.) high by 3.13 inches (7.95 cm.)

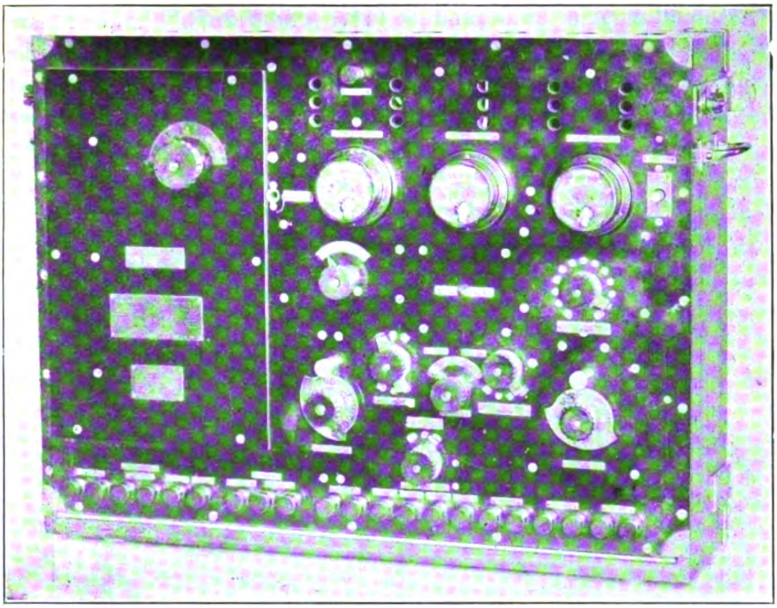

Figure 10A

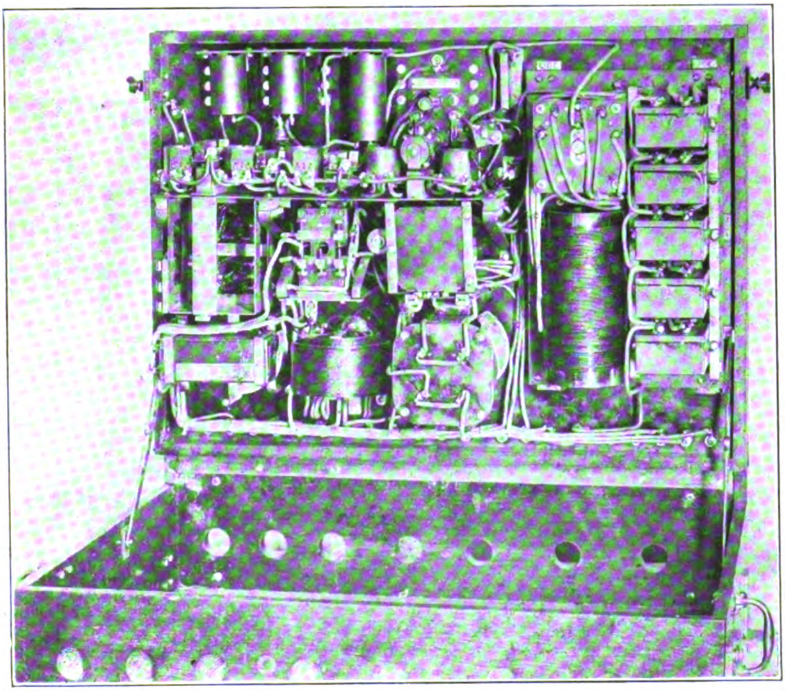

Figure 10B

deep, and weighs 20.5 pounds (11.1 kilograms). Upon it are mounted a filter to minimize high voltage commutator ripple, voltmeter, voltmeter switch, dynamotor transfer switch, power supply protective condensers and fuses. The dynamotors, also

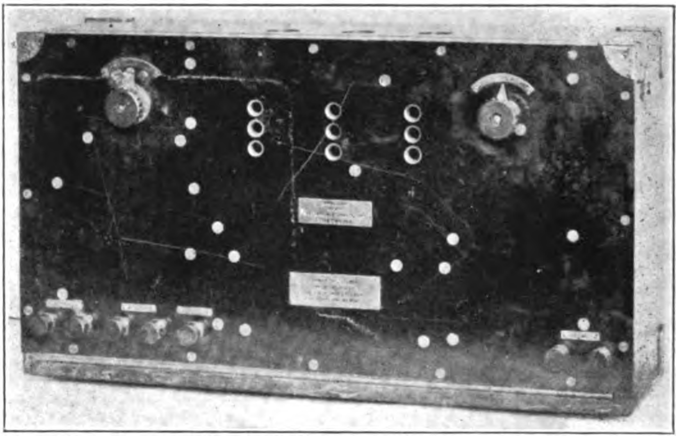

Figure 11A

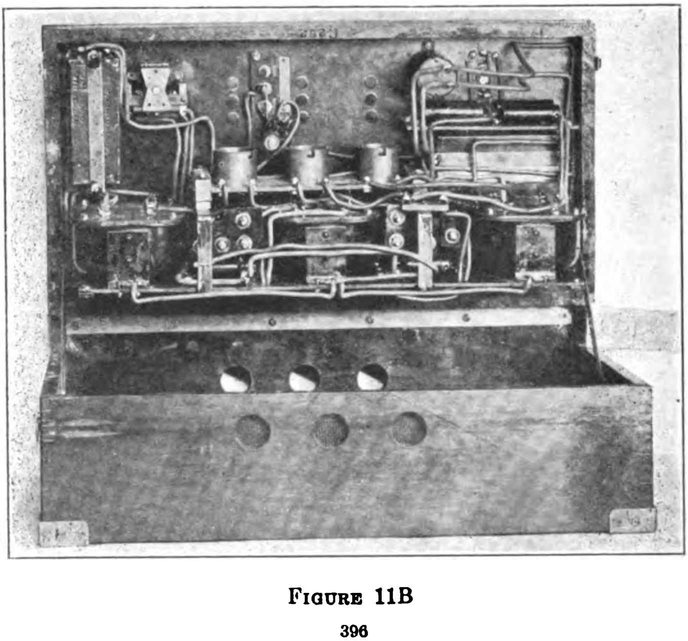

Figure 11B

illustrated in Figure 12, are each 5 inches (12.7 cm.) in diameter and 7 inches (17.8 cm.) long. The dynamotors are spring-suspended in a frame 11 inches (25 cm.) by 15 inches (38 cm.), and the entire unit weighs 33 pounds (14.8 kilograms). Only one dynamotor is used at a time, the other being held in reserve. Power for the filament circuits and for operating the dynamotors is supplied from a 32 volt storage battery. Each dynamotor has an input current of 27.5 amperes at 32 volts and will furnish 0.83 ampere direct current at 350 volts. This dynamotor was designed and manufactured by the Westinghouse Electric and Manufacturing Company.

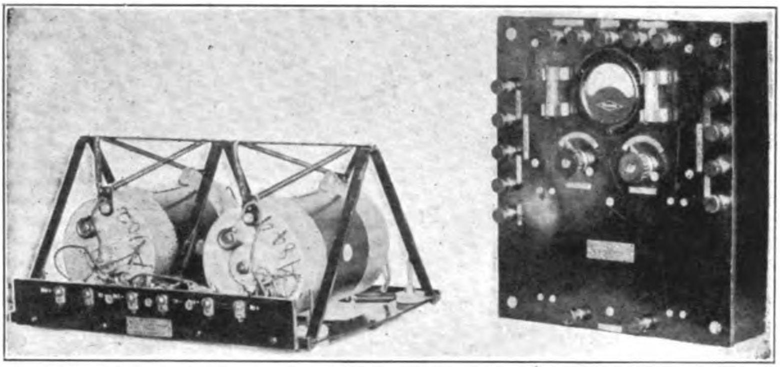

FIGURE 12

The equipment is arranged for remote control by one set of extension apparatus illustrated in Figure 13, which employs primarily a loud speaking telephone. A radio telephone head-set may be plugged in when preferred. The entire equipment is normally in receiving position. In order to transmit, a button is pressed at either the local station or extension apparatus. This apparatus operates a send-receive relay in the transmitter-receiver cabinet.

One of the next higher power vacuum tube transmitters in standard service is a 150 watt (output) type designed and manufactured by the General Electric Company. This equipment is intended primarily for radio telephone communication from battleships, but is also arranged for continuous wave telegraph and buzzer modulated telegraph communication. It is designed for operation on an antenna of the following characteristics:

Fundamental wave length—335 to 477 meters.
Fundamental capacitance—900 to 1,700 micromicrofarads.
Effective resistance—6 ohms.

Six fifty-watt transmitting tubes are employed, three as oscillators, two as modulators, and one as a modulation amplifier.

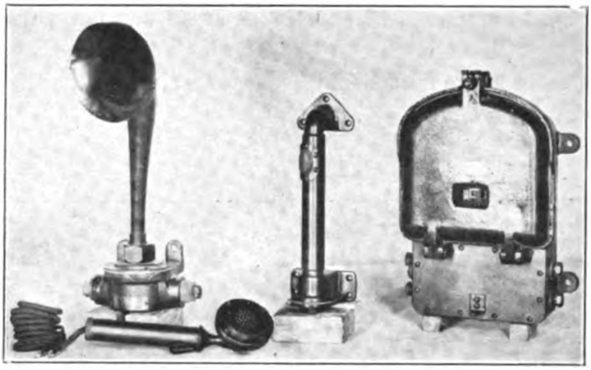

FIGURE 13

The transmitter, illustrated in Figure 14, consists of a cabinet 20 inches (50.8 cm.) wide by 19.25 inches (49 cm.) high by 16.75 inches (42.5 cm.) deep, and weighs 90 pounds (40.5 kilograms). It is constructed on an angle frame to which the bakelite panel and wooden base are permanently fastened. The sides are made of ash and the top of asbestos board. The top and sides are held in place by brass angle pieces, fastened with thumb screws, making them easily detachable. The construction is such that, after the top is removed, the sides and back may be lifted out without further removal of mechanical connections. External connections are made on a bakelite terminal board forming the lower left side of the cabinet.

On the panel front there are located an antenna ammeter, buzzer, antenna and ground binding posts, a wave indicator lamp and button, and the various controls. These are limited to the following very essential controls only. For shifting wave length the large wave change switch handle is used. After using this, the wave indicator button is depressed and more accurate adjustment of wave length made by the antenna variometer control, resonance being indicated by the wave indicator lamp. The wave change switch automatically makes the proper wave indicator connections at each position. The method of communication is chosen by the switch handle in the lower left corner of the panel. This switch also serves to shut down the transmitter when in either of its extreme positions. To the right of this switch is the power change switch by adjustment of which transmission may be conducted on full power or approximately 25 percent or 50 percent full power. The use of full power is restricted unless a lock located on the panel is released by a special key; while the lock is thus released the key cannot be withdrawn; thus full power cannot be used without the approval of a responsible person. Unnecessarily frequent adjustment of grid coupling is discouraged by an insulating plate screwed over the grid coupling control.

The interior of the transmitter illustrates rather interesting construction in apparatus of this type. The generating coil system, antenna variometer, and loading inductance are mounted on the panel together with the control switches and an electromagnetically operated send-receive switch. All switches are of highly improved mechanical construction and are extremely rugged. The six fifty-watt tubes are mounted on a bakelite board, spring-suspended from the cabinet framework to absorb vibration. The tubes are mounted high in the transmitter to permit the most satisfactory dissipation of heat and to render them visible to the operator. The tubes are covered by an expanded metal hood extending above the top of the cabinet. This hood is hinged at the upper back edge to permit replacing of tubes.

Below the tubes on two mounting boards are located the plate reactance, grid leaks, condensers, choke coil, transformer, and other small units. The large antenna series condenser is mounted on the bottom of the cabinet behind the panel. For use in connection with the wave indicator there is mounted on the frame within the transmitter a small cylindrical case containing a variometer type of inductance providing individual adjustment to each wave length.

In the matter of internal wiring, the most careful design has been used. All low voltage control and auxiliary circuits are wired with flameproof wire. The antenna circuit is wired with 0.188 inch (0.477 cm.) diameter copper tubing, the grid and plate circuits with 0.188 inch (0.477 cm.) brass rod. In a few connections 0.080 inch (0.203 cm.) diameter brass rod is used. All wiring is rigidly supported except in the cases of connections to the tube mounting board and coil tap boards where bead-

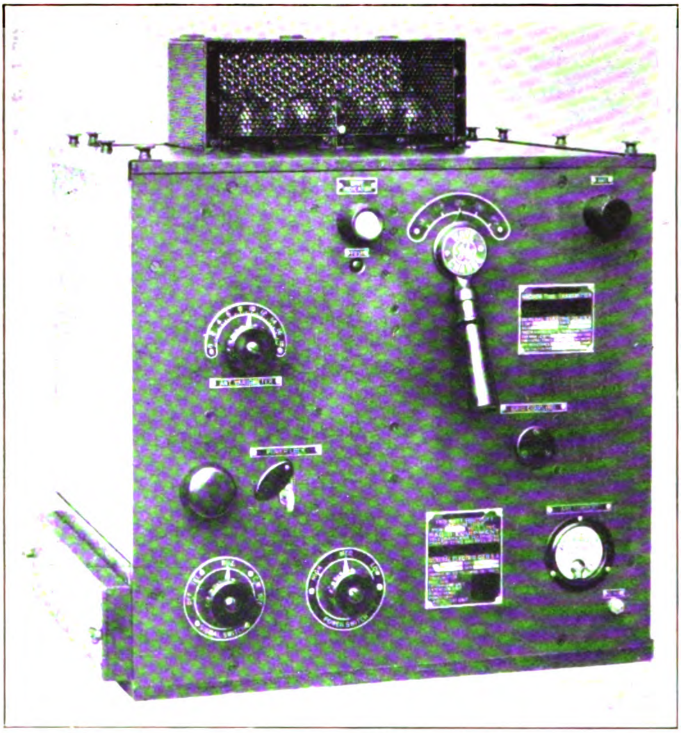

FIGURE 14A

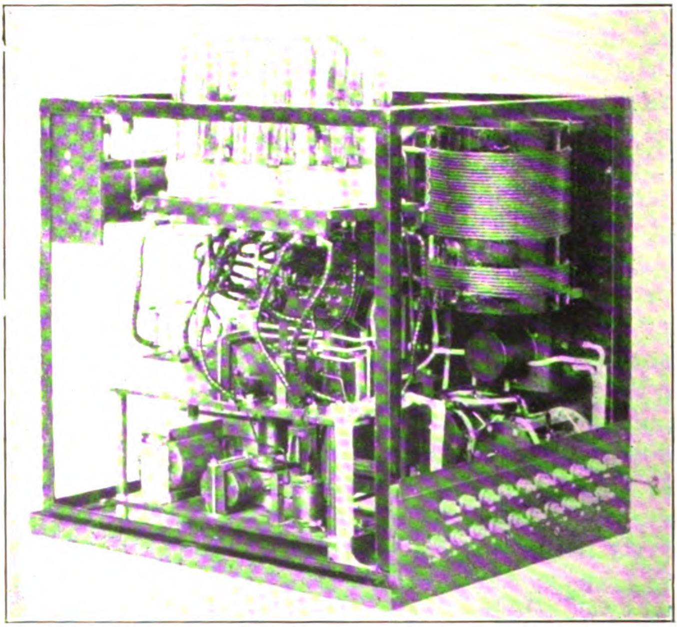

FIGURE 14B

insulated flexible copper braid is used. All bare internal wiring is colored in accordance with the following scheme, thus facilitating the tracing of circuits.

Plate Circuit—Red.
Grid Circuit—Green.
Filament Circuit—Brown.
Antenna Circuit—Blue.
Local Ground Leads—Black.
Auxiliary Circuits—White
Connections on Sub-panel—Yellow.

Another novel feature of this transmitter is the careful labelling of all units as illustrated in Figure 15, thus enabling a person unfamiliar with the apparatus to recognize quickly the various elements.

The schematic circuit used in the transmitter is illustrated

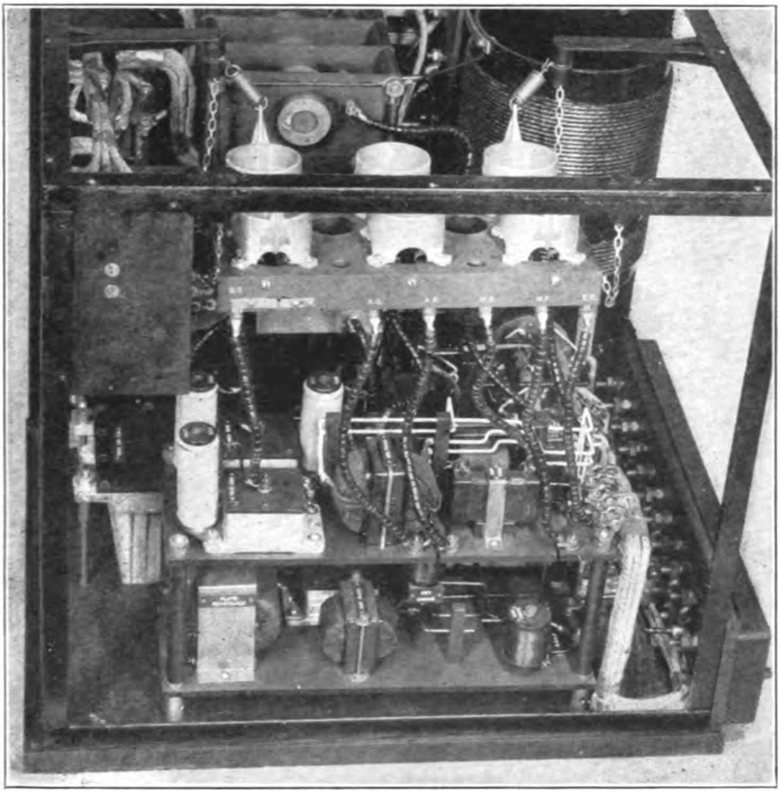

FIGURE 15

in Figure 16. The only novel features of the circuit are the use of individual grid leaks for the oscillator tubes in order to prevent local radio frequency oscillation between the tubes, and the automatic readjustment of grid biasing of modulator and speech amplifier tubes at the time power output is changed by reduction of plate voltage This reduction of plate voltage is effected by insertion of resistance in the field of the plate generator.

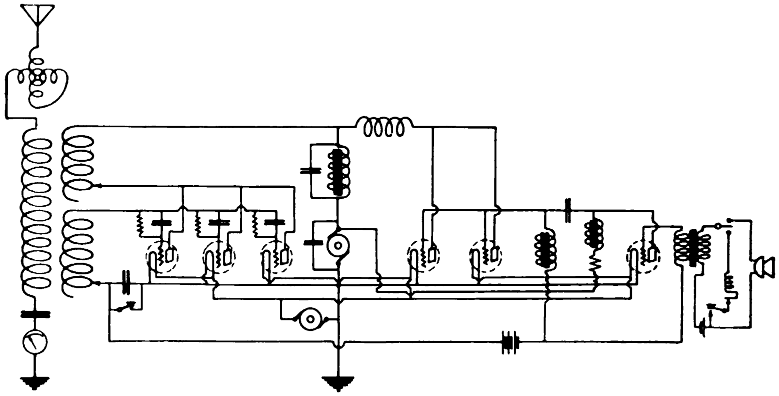

FIGURE 16

The power panel provided with this transmitter and illustrated in Figure 17 is doubtless the first piece of equipment of the kind furnished in this country with a standard tube transmitter. It consists of a panel 24 inches (61 cm.) wide by 37 inches (94 cm.) high, and weighs 220 pounds (99.3 kilograms). It is made of asbestos lumber and mounted on angle iron supports which extend beyond the panel at both bottom and top for installation mounting. On the angle frame extending back of the panel an iron grill is fastened by means of wing nuts, giving the panel an over-all depth of 13.5 inches (34.3 cm.)

On the panel are mounted plate voltmeter, plate ammeter, and filament voltmeter, illuminated by a pilot lamp which acts as an indicator of the fact that line voltage is available. Field rheostats for the filament and plate generators are also mounted on the panel. A double-pole single-throw line switch is located below the rheostat handles. A 9-pole double throw knife switch is provided for selecting either of the duplicate motor generators furnished with this transmitter. An 11-pole double throw knife switch permits the use of either of two complete

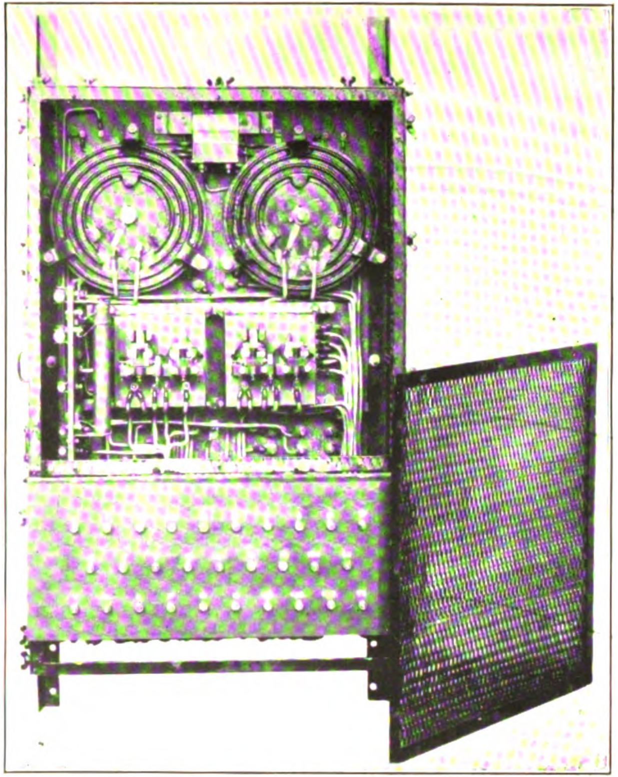

Figure 17A

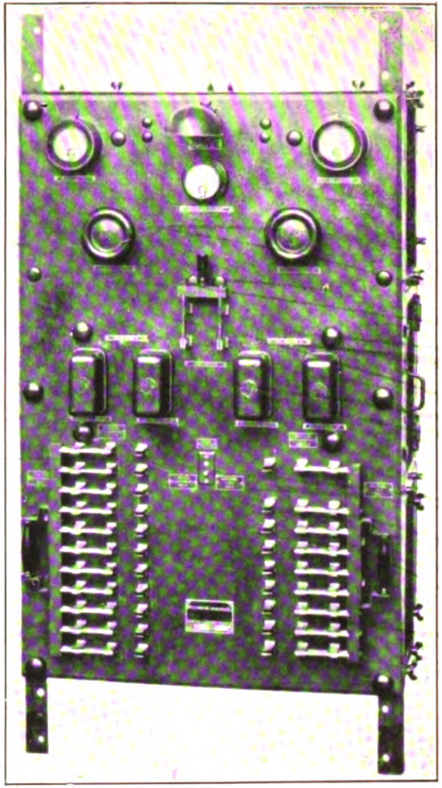

Figure 17B

duplicate starting and control equipments. The motor-generator starting push button switch is located between these large knife switches, above which are mounted the generator field relays.

A spring door in the metal grill affords easy access to a fuse board mounted back of the panel at the extreme right. Terminal connections are made to a terminal board mounted as a sub-panel back of the lower part of the main panel. All wiring on the power panel is lead covered, of single-conductor cable with sheathing grounded.

The motor-generator supplied with this transmitter, illustrated in Figure 18, is 5 feet 10.63 inches (1.79 meter) long, 15 inches (38 cm). wide, and 16 inches (40.6 cm.) high, and weighs 600 pounds (270 kilograms). It consists of a 3 horse-power (2.24 kilowatt) output, 125 volt direct current motor (center), driving two direct current generators, one furnishing 0.75 kilowatt at 24 volts for tube filaments and control circuits, and the other furnishing 1.0 kilowatt at 1,000 volts for the plate circuits of the tubes. The commutator of the high voltage generator is protected by a coarse mesh screen to prevent accidental contact with the commutator brush rigging or other high tension parts.

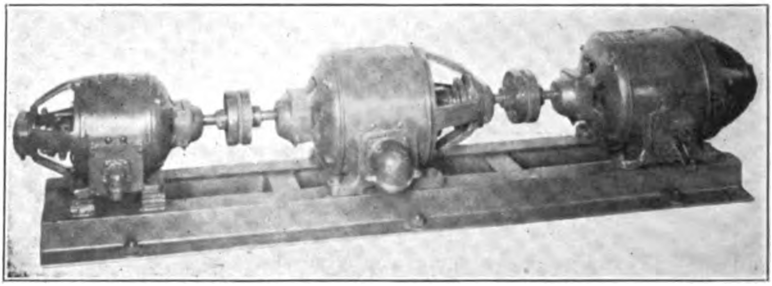

FIGURE 18

To protect the plate generator from high voltage surges there is supplied the protective unit, illustrated in Figure 19, which is 16 inches (40.7 cm.) long by 9 inches (22.8 cm.) high by 4.13 inches (10.5 cm.) wide, and weighs 21 pounds (9.46 kilograms). It is merely a standard four-cell lightning arrester, the design of which is based on the characteristics of a cell consisting of two aluminum plates, on which there has been formed a film of aluminum hydroxide, the plates being immersed in a suitable electrolyte.

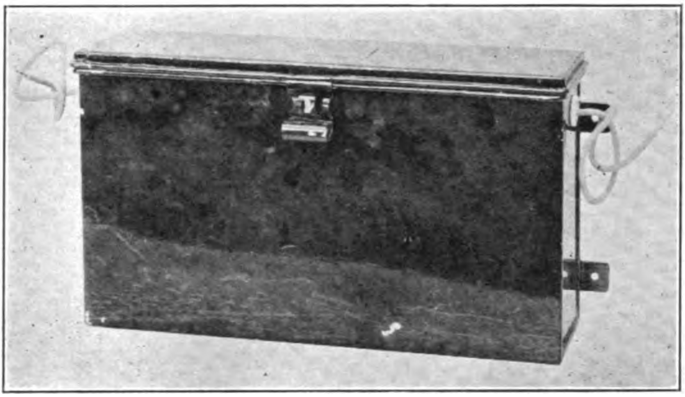

FIGURE 19A

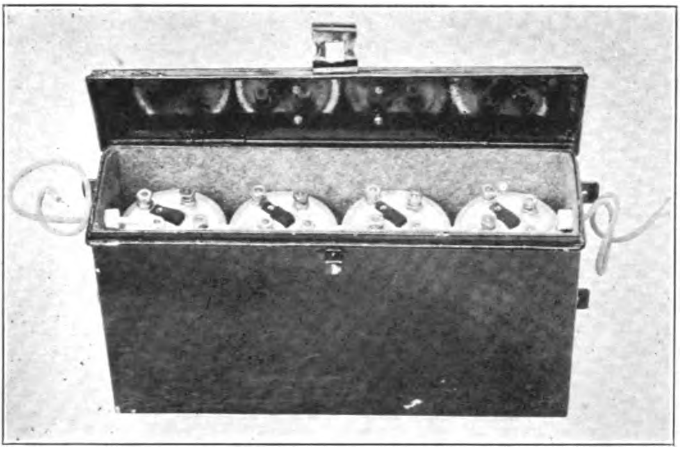

FIGURE 19B

The receiver used with this equipment, illustrated in Figure 20, is contained in a cabinet 14.5 inches (36.9 cm.) wide by 14.5 inches (36.9 cm.) high by 8.75 inches (22.2 cm.) deep, and weighs 22.5 pounds (10.1 kilograms). It consists merely of an inductively coupled vacuum tube receiver with regenerative coupling and two stages of audio frequency amplification. As it is designed to cover only the short wave length range of the transmitter it has been possible to render it quite efficient.

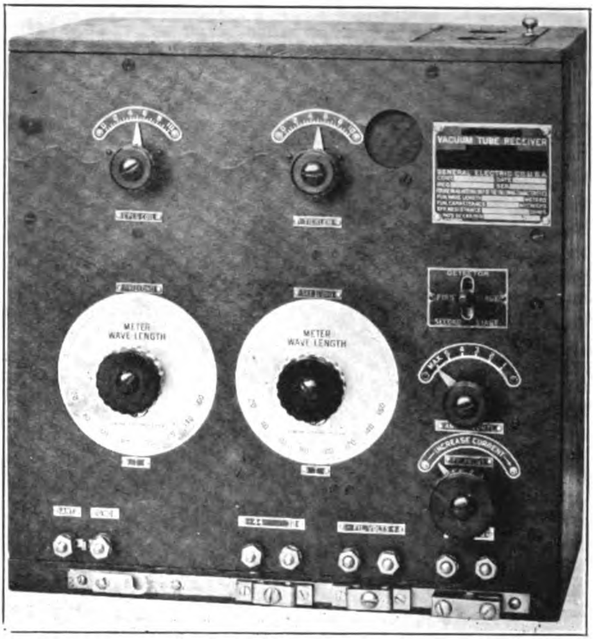

FIGURE 20A

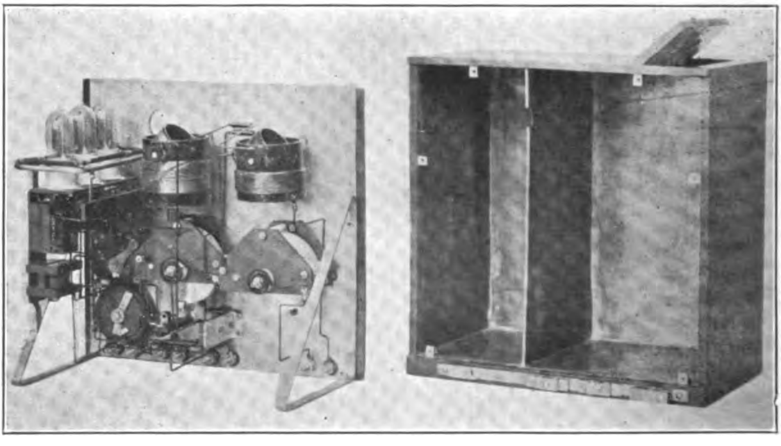

FIGURE 20B

This equipment includes a very important feature in a new standard interphone system which is the result of a very considerable amount of experimental work and represents the only design in this country of a private exchange, as it were, applied to a "radio trunk" for shipboard use. The schematic diagram of the system is illustrated in Figure 21. It involves the use of an interphone unit, shown in Figure 22, mounted in the table, and extension units, as illustrated in Figure 23, designed for bulkhead mounting.

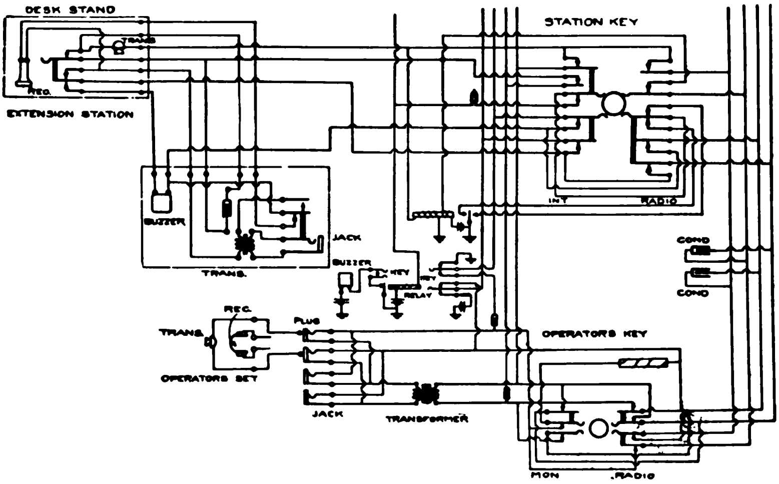

FIGURE 21

The interphone unit consists of a cabinet 11.63 inches (29.6 cm.) wide by 8.25 inches (20.9 cm.) high by 10.63 inches (27.0 cm.) deep, and weighs 20 pounds (9 kilograms). It is designed for mounting so that the panel top, mounting the controls, shall be flush with the surface of the operating table. All external connections, except those to the operator's telephone transmitter and telephone receivers, are made to a terminal board which forms the back of the cabinet. In the front of the cabinet there are mounted two sets of telephone jacks so that two sets of telephone transmitters and telephone receivers may be connected to the unit simultaneously. All of the mechanism and wiring of the unit with the exception of these two sets of jacks is mounted on the panel top in order to permit the removal of the panel top from the cabinet for inspection.

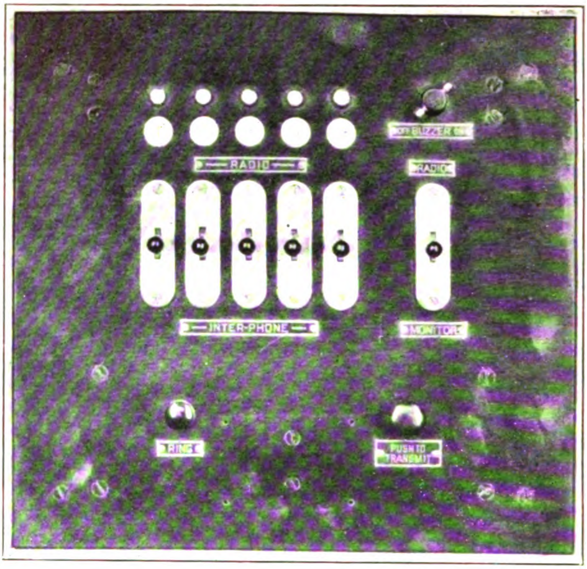

FIGURE 22A

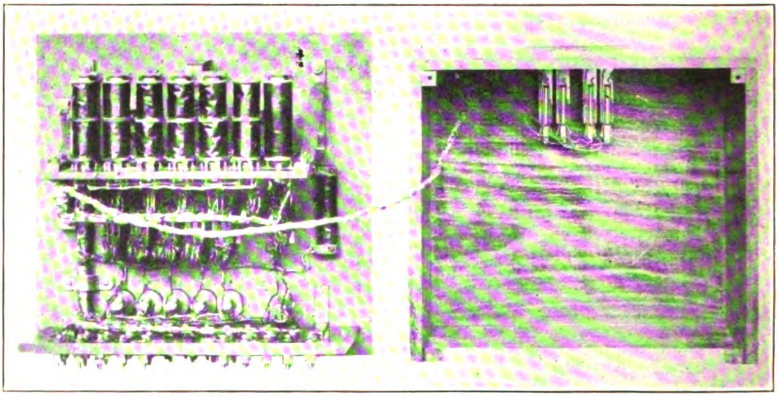

FIGURE 22B

Each extension unit, illustrated in Figure 23 and weighing complete 13 pounds (5.85 kilograms), consists essentially of a standard telephone desk stand mounted on a flexible arm, a buzzer box, and a high impedance telephone head set. On the column of the desk stand opposite the receiver hook, there is provided a push button. When this extension unit is connected for remote control of the radio equipment, the depressing of this button places the send-receive relay in the transmitter in transmitting position. When the button is released, the send-receive relay returns to receiving position.

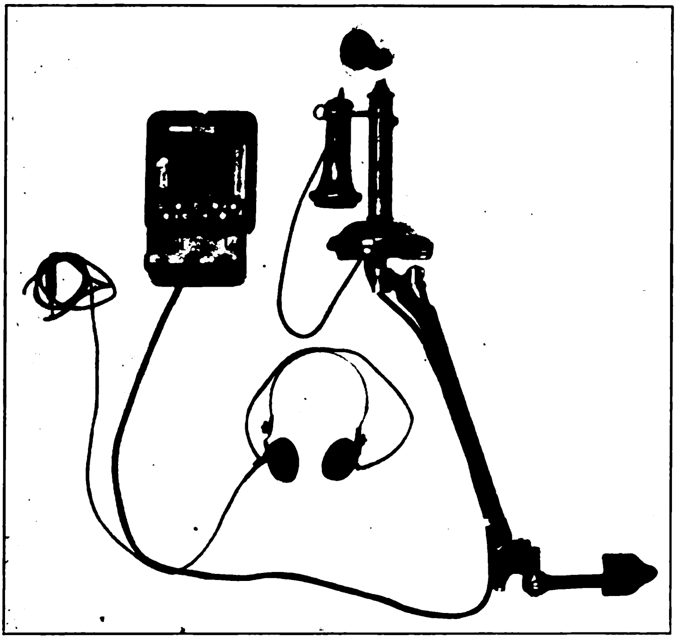

FIGURE 23

The buzzer box is of metal and contains a transformer, a buzzer, a jack, and a terminal board. The transformer is utilized to permit the substitution of the head telephones for the hand receiver. When it is necessary to use the head telephones, the hand telephone is removed from the circuit automatically by plugging the head telephones into the jack in the buzzer box.

The interphone system is arranged for the following method of operation. Upon the removal of the telephone receiver from the desk stand hook at an extension unit the light on the interphone unit corresponding to that station, lights. If the buzzer switch in is "on" position, the buzzer also sounds. Upon the operator throwing the corresponding station key into the "Interphone" position, this lamp is extinguished, and the operator is placed in connection with the extension unit. Upon throwing the station key of a connected extension unit into "Radio" position the extension unit is connected to the radio equipment and is placed in remote control of the send-receive relay in the transmitter. With the station key in the "Radio" position and the extension unit in use, upon the replacing of the telephone receiver upon the extension unit hook, the signal lamp again lights if the operator's key is in other than "Radio" position. The throwing of the station key to the normal position then extinguishes the lamp.

The key on the extreme right of the interphone unit is known as the operator's key and has no signal lamp associated with it. When this key is thrown to "Radio" position, it connects the operator to the radio equipment. When this key is thrown to the "Monitor" position, it permits the operator to listen in on the transmission and reception being conducted from one of the extension units by remote control, but does not place the operator's microphone transmitter in circuit. When the operator's key is in normal position it places the operator in position to be connected to any extension unit in the manner described above.

In order for the operator to ring any extension unit, it is necessary to move the station key corresponding to that extension unit to "Interphone" position and to push the ringing button at the left side of the interphone unit. The transmitting button at the right side of the interphone unit actuates the send-receive relay within the transmitter, and places it in transmitting position when the button is depressed if the operator's key is in "Radio" position. The release of the button restores the send-receive relay to receiving position. When depressed, a slight turn locks the button in transmitting position.

Another higher power standard tube transmitter and one of the most recent design is a 300-watt (output) equipment designed by the General Electric Company in conjunction with the Bureau of Engineering, Navy Department, and manufactured by the General Electric Company. This equipment is arranged for continuous wave telegraph, buzzer modulated, and telephone methods of communication. It is designed for operation on either one of the two antennas, characteristics of which are tabulated in Figure 24.

The transmitter uses twelve fifty-watt transmitting tubes, six oscillators, five as modulators and one as a modulation amplifier. This is doubtless somewhat beyond the economical limit for the use of fifty-watt tubes in parallel, but the difficulty of storing spare tubes of larger sizes aboard certain small craft and other minor considerations led to the use of the fifty-watt tube in this set.

Antenna	Fundamental Wave Length	Fundamental Capacitance	Effective Resistance (Maximum)
A	204-230 meters	450- 500 micromicrofds.	4 ohms
B	250-2650 meters	800-1850 micromicrofds.	4 ohms

FIGURE 24

The transmitter and power panel, illustrated in Figure 25, comprise a combined unit, mounted on pipe or angle supports. The transmitter, the upper unit shown, is 26.75 inches (68 cm.) wide by 21.26 inches (54 cm.) high (over-all) by 17.25 inches (43.7 cm.) deep, and weighs approximately 150 pounds (67.6 kilograms). It is constructed on an angle frame to which the sheet brass panel and base are permanently fastened. The sides, back, and top, of expanded metal grillwork, are removable by means of thumbscrews on the frame. External connections are made on a bakelite terminal board forming the lower left side of the transmitter.

On the panel front there are located an antenna ammeter, buzzer, wave indicator lamp and switch, and antenna post. There are also located on the panel the following essential controls. The large wave change switch handle is used for the purpose of shifting wave length. After using this, the wave indicator switch is moved to the wave length position in question, and a more accurate adjustment of emitted wave length is made by the antenna variometer control, resonance being indicated by the wave indicator lamp. The wave indicator switch is then thrown to an "off" position at either extremity of throw. This arrangement of wave indicator has been found to be more satisfactory on the whole than that previously described. The method of communication is chosen by the switch handle in the lower left corner of the panel. This switch also serves to shut down the transmitter when in either of its extreme positions. Above this witch is the power change switch, by which transmission may be conducted on full power or approximately 25 percent or 50 percent full power. A full-power lock similar to that previously described is located between the signal and power switches. On the front of the panel is also mounted the grid relay used in con-

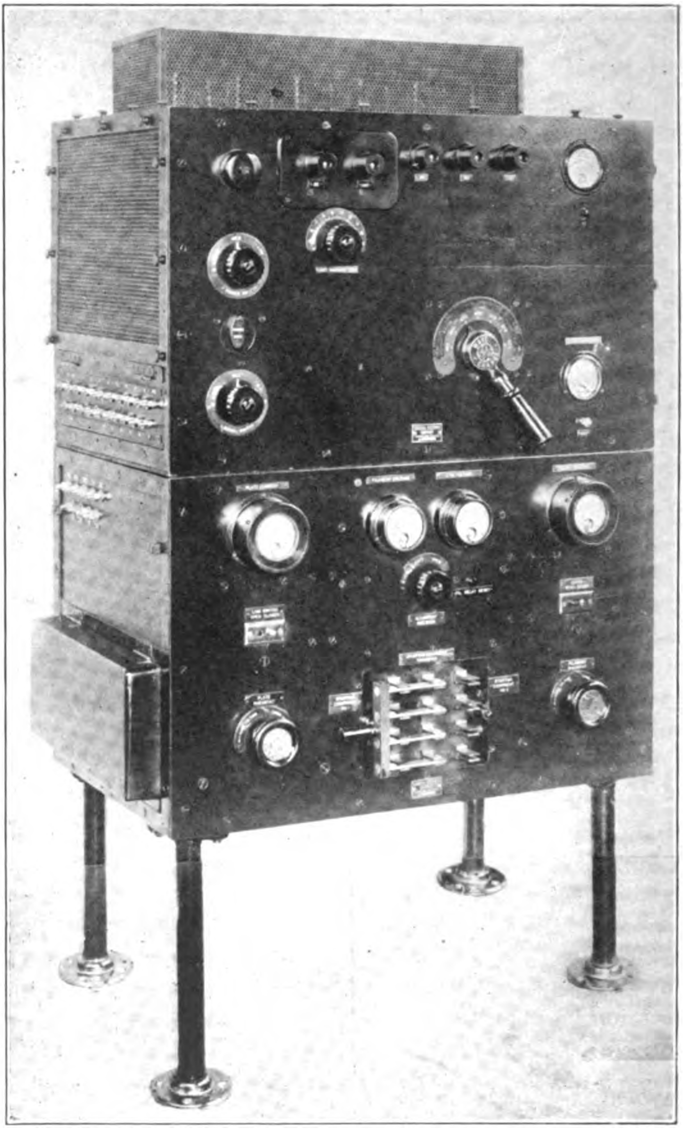

FIGURE 25

nection with the break-in system described later. The relay is so connected that in event of failure it may be replaced instantly by a spare relay supplied with the equipment.

The interior of the transmitter is fundamentally similar to that of the 150-watt equipment, but the arrangement of apparatus is somewhat different and several improvements have been incorporated. The twelve fifty-watt tubes are mounted on a spring-suspended board high in the transmitter, and are covered by an expanded metal hood extending above the transmitter and hinged at the back.

The schematic circuit used in the transmitter is illustrated in Figure 26, and differs from that used in the previously-described equipment in that the grid circuit receives its excitation from a portion of the antenna circuit inductance thru a capacitive coupling. This method of grid excitation has proven markedly superior to that used in any other Navy tube transmitters designed thus far. Two features are worthy of note. To prevent local radio frequency oscillations between the tubes, it has been found more satisfactory to use a small choke coil in the grid connection to each tube rather than to use individual grid leaks.

The power panel, the lower unit in Figure 25, is mounted directly beneath the transmitter and is 26.75 inches (68 cm.) wide by 18.5 inches (47 cm.) high by 17.25 inches (43.8 cm.) deep. It weighs approximately 150 pounds (67.5 kilograms). It is structurally similar to the transmitter, constructed on an angle frame with a sheet brass panel on which are mounted line, filament and plate voltmeters, plate ammeter, remote control buttons for the main line switch and motor starter, and control handles for filament and plate generator field rheostats. On the front of the panel are also mounted a filament protective relay re-set button and a starting equipment transfer switch. The front of the power panel is illuminated by two lamps connected on the power supply line and therefore acting also as pilot lamps.

The protective filament relay disconnects the power supply from the tube filaments when the terminal voltage exceeds 10.5 volts. By field rheostat adjustment, the filament voltage may be reduced to its normal value of 10.0 volts and the protective relay reset by the button provided.

Within the power panel structure are located a main line contactor, two automatic starters in duplicate, each provided with a no-load release, and filament and plate generator field rheostats, filament voltage protective relay, high voltage filter system, resistance for break-in system, and other minor units.

Input terminals of the power panel are mounted on the bottom and output terminals on the upper left side near the transmitter terminal board. The necessary fuses are mounted on the left side of the power panel beneath a protective hinged cover.

Thruout the entire equipment no contact is broken outside of a gauze enclosed space and a novel feature of the starting equipment transfer switch, of the open knife blade variety on the front of the power panel, is that, before the contacts break on either side, the switch bar releases a button in the panel behind it which opens the main line contactor. The switch thus ceases to carry current before the switch blades leave the jaws.

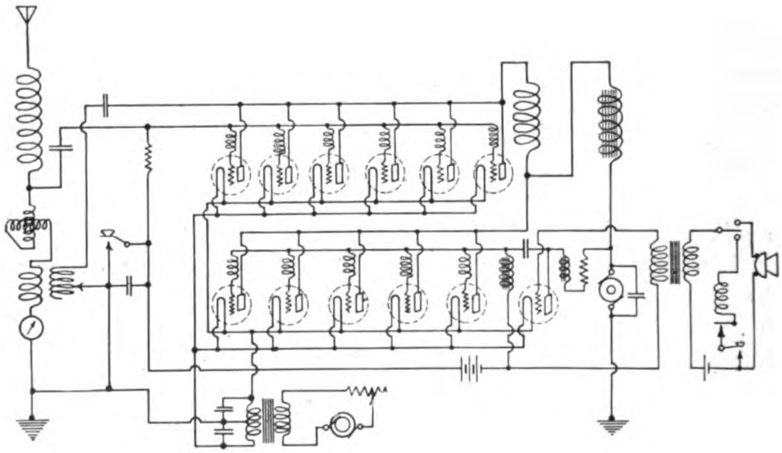

FIGURE 26

The motor-generator supplied is the two-unit equipment illustrated in Figure 27. It is 4 feet, 10.31 inches (1.48 meter) long by 19 inches (48.2 cm.) wide by 17 inches (45.2 cm.) high, and weighs approximately 575 pounds (238 kilograms). It consists of a 3.75 horse-power (2.8 kilowatt output) direct current motor driving a direct current generator furnishing 1.5 kilowatt at 1,000 volts. The motor is provided with a mechanical speed regulator which maintains its speed constant thruout a supply line voltage variation of 105 to 150 volts, the normal operating line voltage being 120.

From slip rings on the direct current motor, there is available for filament lighting approximately 850 watts at 85 volts, 35 cycles alternating current. By use of the filament transformer and rheostat, this power is made available at 10.0 volts at the filament terminals.

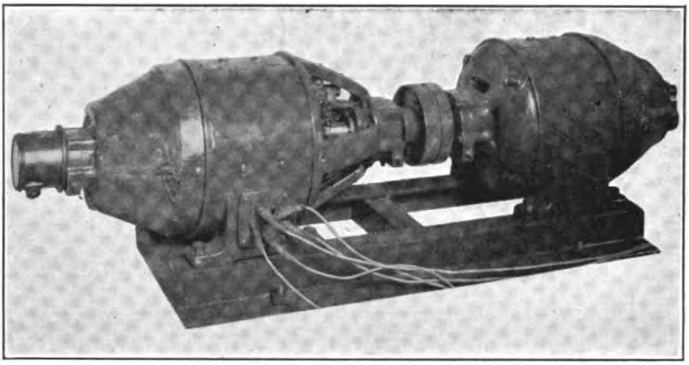

FIGURE 27

A novel feature of this transmitting equipment is the break-in system used in connection with it so that radio reception may be conducted on the transmitting antenna between the dots and dashes of the transmitted signal. The schematic circuit of this system is shown in Figure 28. When the back contact of the key is closed, the power supply to the antenna-break relay coil is short circuited thru the relay resistance, this relay is de-energized and opens the short circuit across the primary of the receiver.

When the back contact of the key is opened, the short circuit on the power supply to the antenna-break relay coil is removed, and this relay short-circuits the receiver primary.

When the front contact of the key is closed, the grid relay is energized. At first the upper or interlock contacts are opened, thereby insuring the placing of the antenna-break relay in transmitting position. Then the lower contacts are closed, short-circuiting the keying condenser of the radio transmitter and sending out the desired signal.

Assuming that all relays associated with the system operate at the same speed, it is evident that the time interval elapsing between the opening of the back key contact and the closing of the front key contact insures the opening and closing of the contacts of the antenna-break relay when no transmitting current is flowing thru them, thereby resulting in much longer life of these contacts. The interlock contacts on the grid relay act as an additional safeguard to this operation and in event of the grid relay accidentally remaining in transmitting position, prevents the return of the other relay to receiving position.

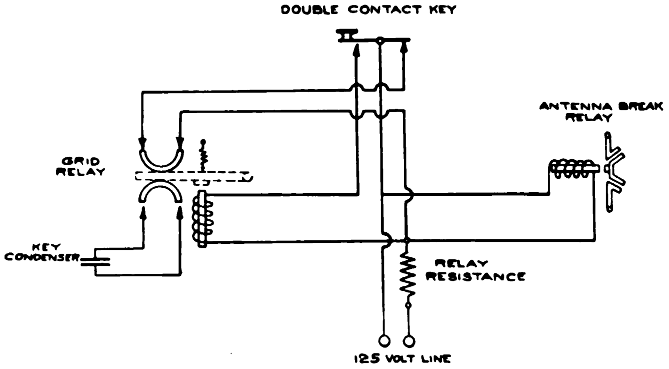

FIGURE 28

The relay resistance prevents the absolute short-circuit of the power supply and acts to reduce the supply voltage to the proper value for the operation of the relays when the front key contact is closed.

The two relays used are illustrated in Figure 29. They are the result of a most careful design and exhaustive test work, and operate with a high degree of satisfaction.

One of the highest power naval tube transmitting equipments is one of 750 watts output for telephone and 1,500 watts for continuous wave telegraph, designed primarily for shore station work. This set was originally developed for use at Naval air stations, and has been briefly described in a previous paper[3] by the author. The apparatus has now been improved materially in design and its use extended to all classes of Naval shore stations.

Operation is arranged for on any one of six wave lengths from 500 meters to 2,700 meters. For the most efficient operation thruout this wave length range, it has been decided to utilize two antennas, one for all wave lengths below 1,000 meters as illustrated in Figure 30, and another for all wave lengths of 1,000 meters or above as typically illustrated in Figure 31.

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[3] See T. Johnson, Jr., "Naval Aircraft Radio," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1920, volume 8, number 2, page 128.

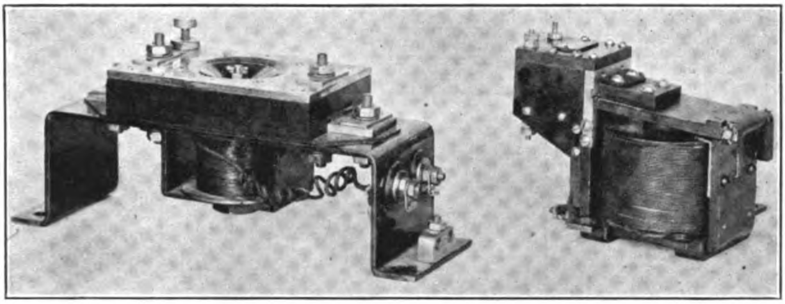

FIGURE 29A

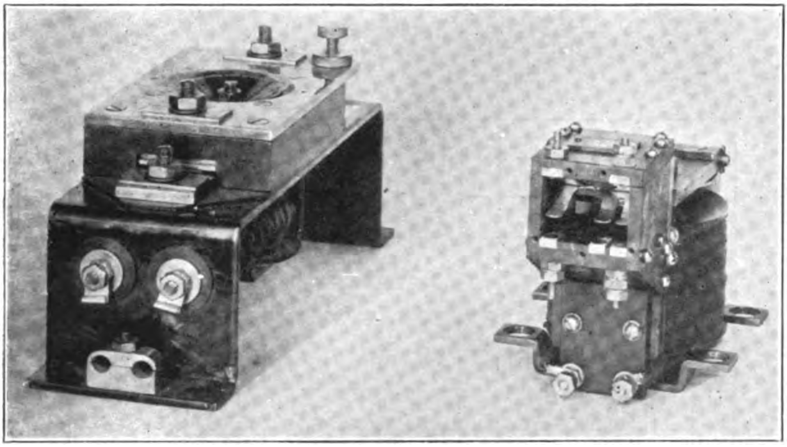

FIGURE 29B

Inasmuch as an antenna, approximating either one of the two types, is existent at any Naval shore radio station, the installation of this equipment has not required the construction of more than one additional antenna in any case.

Transmission is provided for on either continuous wave telegraph, buzzer modulated continuous wave telegraph, or telephone at either approximately 25 percent, 50 percent, 75 percent, or full rated output. A reliable daylight communication range over water of 1,000 nautical miles (1,850 kilometers), using continuous wave telegraph, and of 200 nautical miles (370 kilometers) telephone has been consistently experienced.

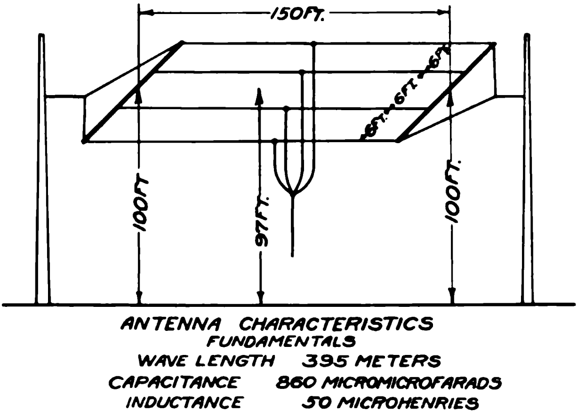

FIGURE 30

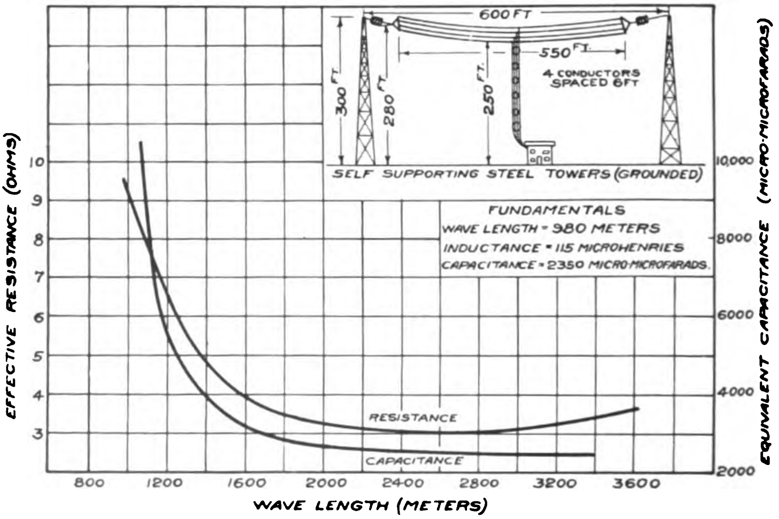

FIGURE 31

This transmitter employs six 250-watt tubes, Type CG 916, all of which are used as oscillators for continuous wave telegraph. For telephony, three are used as oscillators and three as modulators. Power is supplied to the plate circuits of these tubes, at 2,000 volts direct current. A 5-watt tube, Type CG 1162, is used as a modulation amplifier. The schematic circuit used is shown in Figure 32.

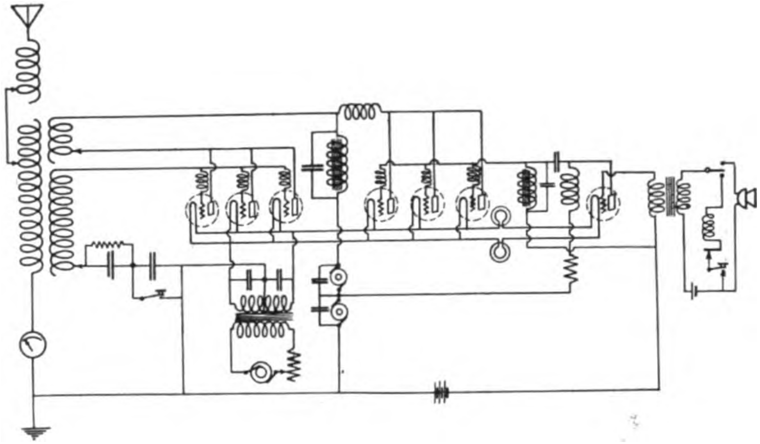

FIGURE 32

The radio transmitter proper, illustrated in Figure 33, is approximately 3 feet 1.75 inches (1 meter) wide by 3 feet 6 inches (1.07 meter) high by 2 feet 11.63 inches (94.4 cm.) deep, and weighs approximately 500 pounds (225 kilograms). It consists of a bakelite panel mounted on an angle iron frame and supported on pipe leg supports.

The upper panel section is devoted to instruments and the essential controls which are required regardless of the number of wave lengths used. Each of the two lower panels accommodate the coil systems and controls for three or less wave lengths.

On the front of the upper panel section are mounted filament and plate voltmeters, antenna ammeter, and plate ammeter. Plate ammeters for the individual transmitting tubes are mounted in protective glass-covered cases on each side of the panel. The three large control handles from left to right are the manual send-receive-ground switch, the signal switch for selecting the method of communication, and the wave change switch. A telephone transmitter is mounted on an adjustable bracket at the left, altho any other type of microphone may be used by plugging its terminals into a jack provided in the panel and throwing a flush button switch mounted near the left lower edge of the upper panel section. A telegraph key is mounted on a small section of the panel which hinges out during operation into a horizontal position. Provision is also made for using an externally mounted key. The buzzer for buzzer modulation is mounted on the front of the upper section panel as is also a single rheostat control for the filament current of the large transmitting tubes. The filament current of the modulation amplifier 5-watt tube is controlled by ballast lamps. On this panel section are also mounted a grid biasing potential switch and a double button

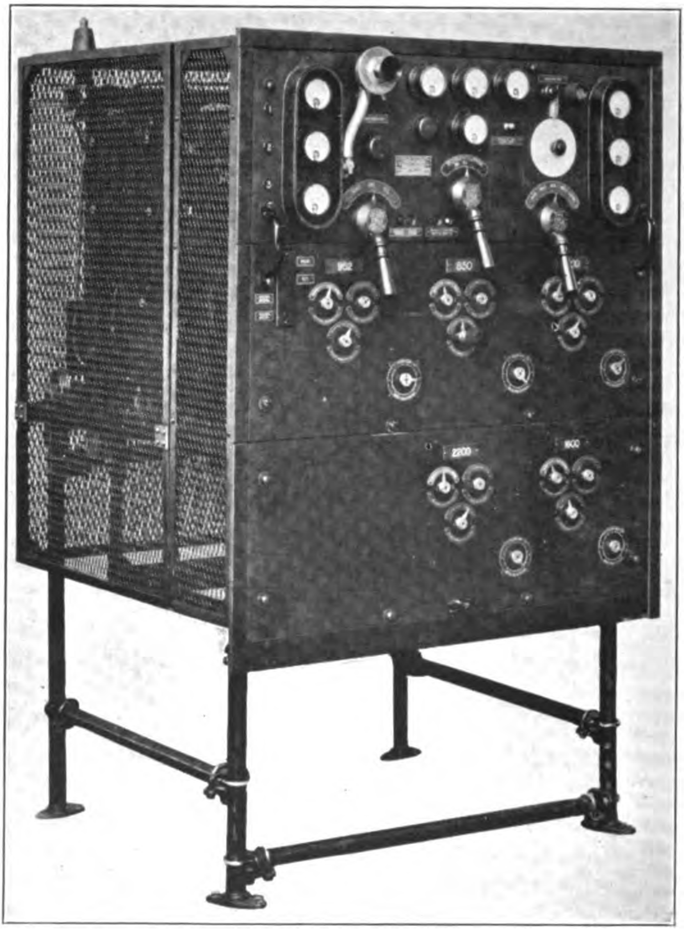

FIGURE 33A

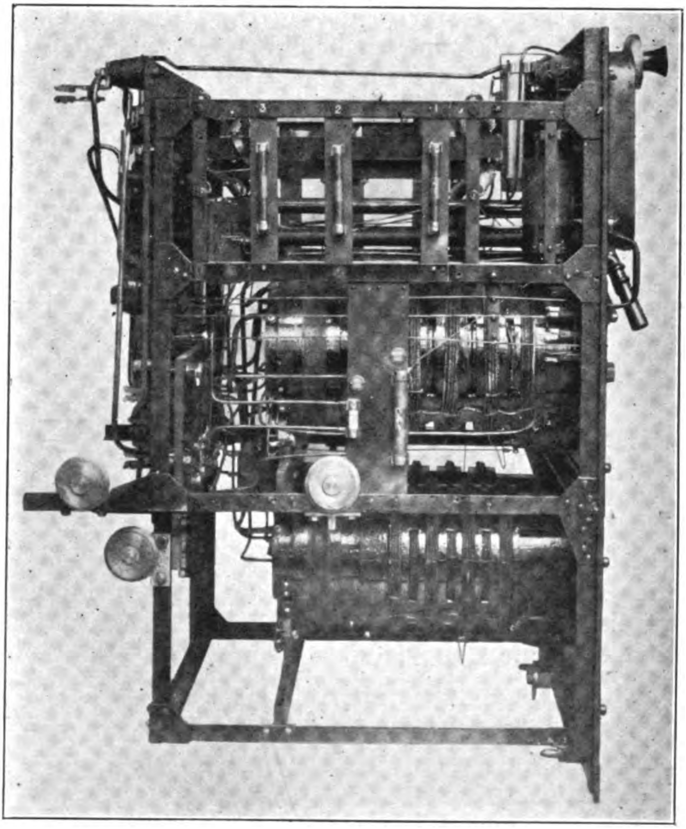

FIGURE 33B

by which the motor-generator may be started by the regular starter or by remote control from the send-receive switch.

At the right side of the upper panel section there is mounted a wave meter which includes an inductance coupled to a single turn in the antenna circuit, a variable condenser, and an incandescent lamp as a resonance indicator. The inductance is adjustable by steps, its control moving a pointer radially on the condenser scale to various circles on which are marked various calibration points thruout the wave length range of the transmitter. Very accurate adjustments of wave length may thus be made quickly and easily.

Behind the upper panel section are mounted the tubes on a spring-suspended cradle, fuses, rheostats, reactances, and so on.

The two lower panel sections are identical in general features, each having mounted behind it the coil systems for three wave lengths and having mounted in front three controls for each coil system, that is, antenna variometer, switch for plate coil taps, and switch for grid loading coil taps.

The entire transmitter is enclosed by an iron grill and is built similar to a truck type switchboard in that the entire panel and apparatus mounted behind it may be rolled out of the protecting grillwork, this motion entirely disconnecting the transmitter from the power supply terminals which are mounted on the back of the grill cage, within. The transmitter is then safe for inspection or repairs, but may instantly be connected again to the power supply by rolling it back into the cage.

As regards internal construction, the transmitter is very similar to those just described. It embodies all the features of heavy rigid wiring, colored according to circuit, clear and careful marking of all units with name or function, and so on.

The motor-generator supplied with this equipment varies according to the source of power at the point of installation. Where direct current is available at 110 or 220 volts, the motor-generator, illustrated in Figure 34, is furnished. This machine is 5 feet 5 inches (1.65 meter) long by 20 inches (50.8 cm.) wide by 19 inches (48.2 cm.) high, and weighs 1,024 pounds (462 kilograms). It consists of a 6 horse-power (4.48 kilowatts output) motor, direct connected to a high voltage generator which from two 1,000-volt commutators in series will deliver 3.5 kilowatts at 2,000 volts direct current. The generator is excited from the direct current supply line. The direct current motor is provided with slip rings from which alternating current at 85

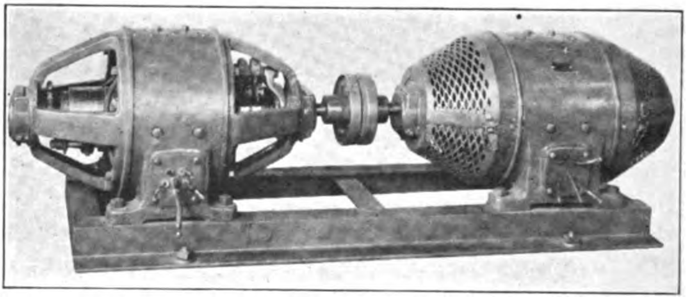

FIGURE 34

volts 35 cycles is taken to a transformer from which, at 24 volts, the filaments of the tubes are lighted.

At installation points where only an alternating current supply of power is available the same high voltage generator is provided, driven by an alternating current motor. In this case, however, the high voltage generator is self-excited from one of its 1,000 volt commutators, and the alternating current for filament supply is furnished thru a suitable transformer, from the power supply line.

An eight-cell protective unit, illustrated in Figure 35, is furnished with this equipment. It is 3 feet 10 inches (1.17 meters) long by 12 inches (31.6 cm.) wide by 18 inches (45.8 cm.) high, and weighs 95 pounds (42.7 kilograms). It is similar to the four-cell unit previously described and consists of eight aluminum cells in glass jars. A 10,000 ohm resistance is connected across each cell.

With each equipment there is furnished the starting panel shown in Figure 36. This is contained in a sheet metal box 22 inches (51 cm.) wide by 29 inches (73.7 cm.) high by 16 inches (40.6 cm.) deep, and weighs 117 pounds (52.7 kilograms). It

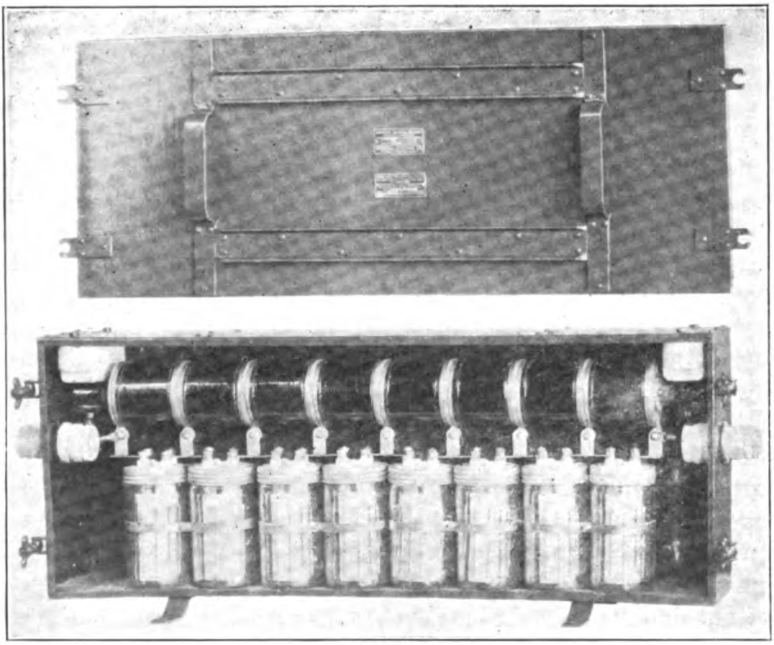

Figure 35

contains in addition to a main line switch and fuses all of the necessary units for hand or remote control starting of the motor-generator, including a hand switch and a remotely controlled switch for making the control transfer. It also contains a plate generator field rheostat by which the power output of the equipment is adjusted.

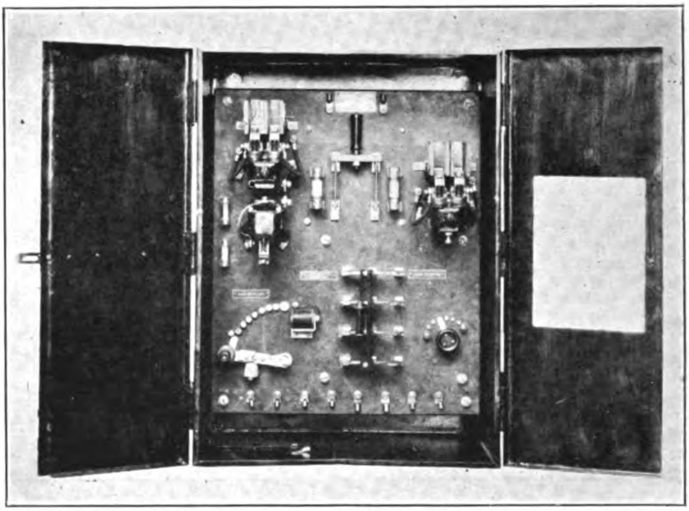

FIGURE 36

The cable connections between the various units of this equipment are illustrated diagrammatically in Figure 37. In this diagram are included the various units of the remote control system which was developed so that it would be possible to use this radio equipment in conjunction with a standard radio receiver for radio telephone transmission and reception, operating over a public or private two-wire telephone line. The system is arranged so that a send-receive switch at the transmitter can thus be remotely controlled without the use of additional wires. To remotely control the radio set in this way, a subscriber must be provided with a small amount of special additional equipment and the system is designed for guaranteed successful operation only if the connection is limited to one telephone exchange standard cord circuit and two telephone lines of not more than 250 ohms each. The system fulfils, however, the demands of the Naval service for which it was designed, and will ordinarily give successful operation thru a connection exceeding these limits.

The schematic circuit of this system is shown in Figure 38. The subscriber's station is equipped with a foot switch by the motion of which, either up or down, a momentary impulse of 60 cycle alternating current from a local lighting circuit is sent over the telephone line. This impulse operates a series of two relays which actuate the radio send-receive switch, alternately placing it in transmitting and receiving position as impulses are successively received. If operating in the proper synchronism, a downward movement on the foot switch therefore places the send-receive switch in transmitting position, and an upward movement places the send-receive switch in receiving position.

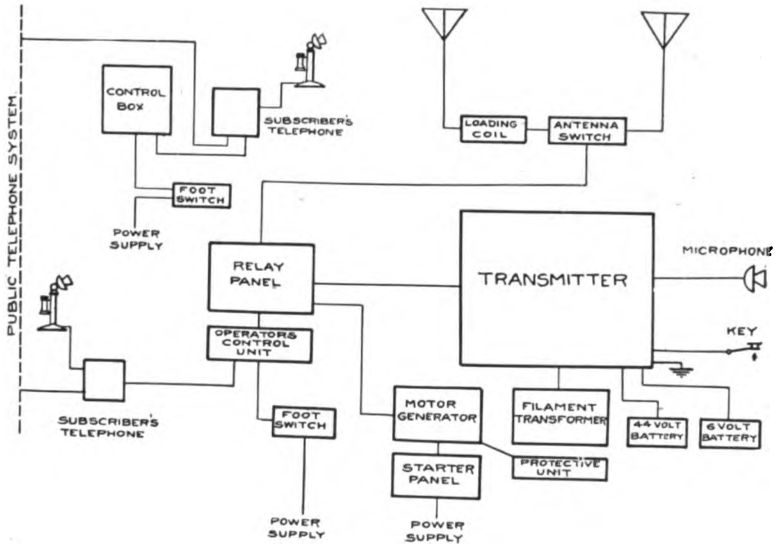

FIGURE 37

At the subscriber's station the supply is coupled to the telephone line thru a suitable transformer, the magnitude of the impulse on the line at this point being about 0.25 ampere at 110 volts and the interval about 0.04 second. In order to get sufficient energy over the telephone lines and thru the repeater coils in the telephone exchange at this low frequency it is necessary to tune the lines with capacitance as much as possible. In cases where only a direct current supply of power is available at the subscriber's station, the foot switch is arranged mechanically to transmit a few pulses of direct current over the telephone line in place of the alternating current pulse.

Each subscriber's station desiring the possibility of radio connection must be equipped with only two additional pieces of apparatus, a foot switch and a control box. The foot switch

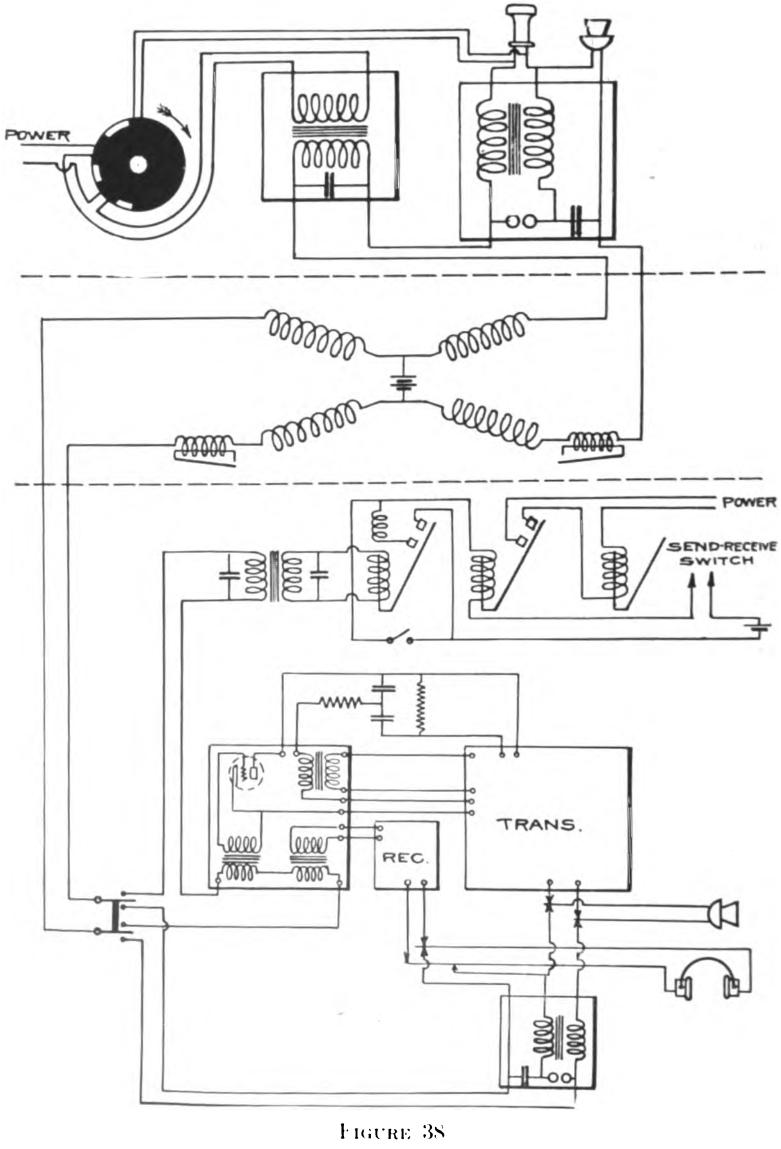

FIGURE 38

is shown in Figure 39. Its over-all dimensions are 3 inches (7.6 cm.) wide by 3.25 inches (8.27 cm.) high by 7.5 inches (19 cm.) long, and its weight is 5.5 pounds (2.48 kilograms). By the use of springs it is so arranged that the switch does not act until the foot pedal has passed thru approximately two-thirds of its range of motion. The contacts are fixed members and are closed by sectors on the moving drum. The foot switch momentarily connects the supply line leads to the control box transformer, and simultaneously short-circuits the telephone receiver, with sufficient lap to insure the absence of objectionable intensity in the resulting click.

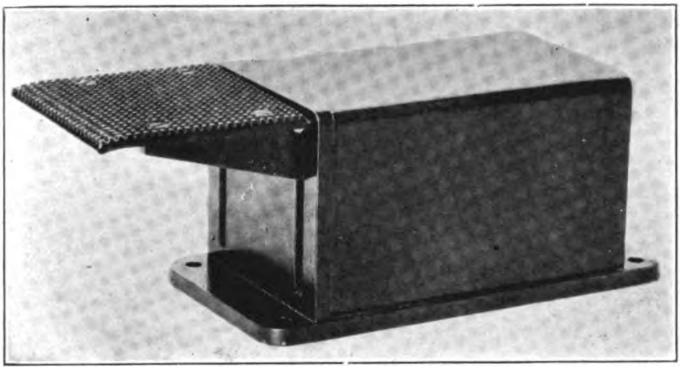

Figure 39A

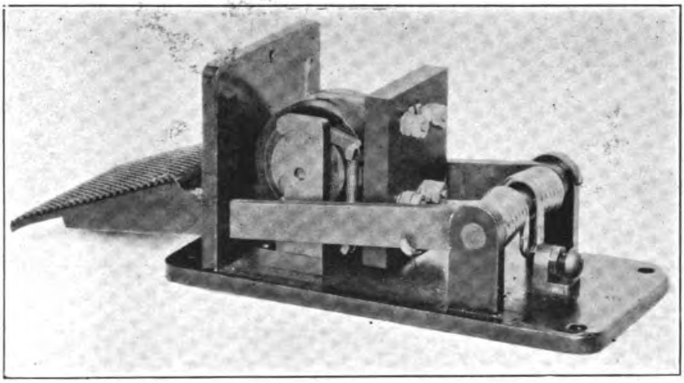

Figure 39B

The control box, illustrated in Figure 40, is a sheet metal box 6 inches (15.2 cm.) wide by 11.25 inches (28.6 cm.) high by 4.25 inches (10.8 cm.) deep, and weighs 11 pounds (5 kilograms). It contains merely a transformer and tuning condensers. The transformer transfers the alternating current pulse from the supply line via the foot switch to the telephone line. The foot switch and control box are connected to the subscriber's regular telephone illustrated in Figures 37 and 38.

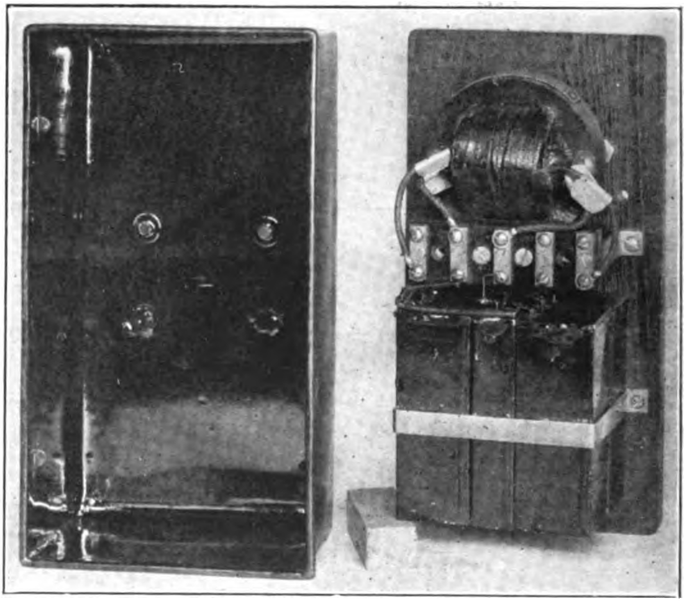

FIGURE 40

For use in this system, three additional units are required at the radio station, an operator's control unit, a relay panel, and a foot switch. The operator's control unit, illustrated in Figure 41, is enclosed in a sheet brass box 10 inches (25.4 cm.) wide by 11.25 inches (28.6 cm.) high by 4.25 inches (10.8 cm.) deep, and weighs 23 pounds (10.3 kilograms). On the front of the box are mounted the filament rheostat control for the amplifier tube within, three-position telephone keys, one two-position telephone key, and two jacks. From left to right the functions of the telephone keys are as follows: The first key is for connecting the breast microphone transmitter and head receivers of the radio operator to the radio equipment or to the telephone line. The second key is for connecting the radio equipment for either local or distant control. The third key is for connecting the incoming telephone line at the radio station to either the local subscriber's telephone set or to the radio equipment. The red-handle key to the extreme right is a two-position self-restoring key and, when moved down and released, actuates the position relay once. The key may thus be used for synchronizing the control system or as an emergency send-receive switch. The jacks are for the radio operator's breast microphone and head receivers.

Viewing the box from the rear, in the upper part is mounted the transformer connecting the radio receiver to the telephone line and a smoothing-out reactor. A 5-watt transmitting tube, used as a voice amplifier between the telephone line and the transmitter, is mounted on a spring suspended support in the upper part of the box. On the bottom of the box are mounted the amplifier input and output transformers. The terminal board is mounted on the right side. The entire top is hinged for inspection and tube renewal, and the portion directly above the tube is perforated.

The relay panel, illustrated in Figure 42, is enclosed in a sheet metal box 24.75 inches (62.8 cm.) wide by 20.75 inches (52.7 cm.) high by 9.5 inches (24.1 cm.) deep, and weighs 135 pounds (61 kilograms). The panel is made of 1.5 inch (3.8 cm.) blue Vermont marble across the upper part of which is mounted the shaft on which the send-receive switch contacts are operated. The shaft is made of hickory, specially oil-treated.

The impulse from the telephone line enters thru terminals on the lower right edge, thru the transformer and tuning condensers to the right of the lower barrier, and actuates the telephone relay at the bottom of the panel to the left of the terminals. As the telephone relay closes it actuates the position relay above it and also energizes a "holding-in" coil on its own core. The position relay, dependent upon its previous position, either energizes or de-energizes the solenoid directly above it, resulting in the rotation of the contactor shaft in one direction or the other. In either case one of the sets of contacts to the left of the solenoid disconnects momentarily the "holding-in" coil of the telephone relay, allowing the armature of that relay to fall back into position to receive another impulse from the telephone line. Another small set of contacts at that point in the shaft short-circuits either the primary winding of the ampli-

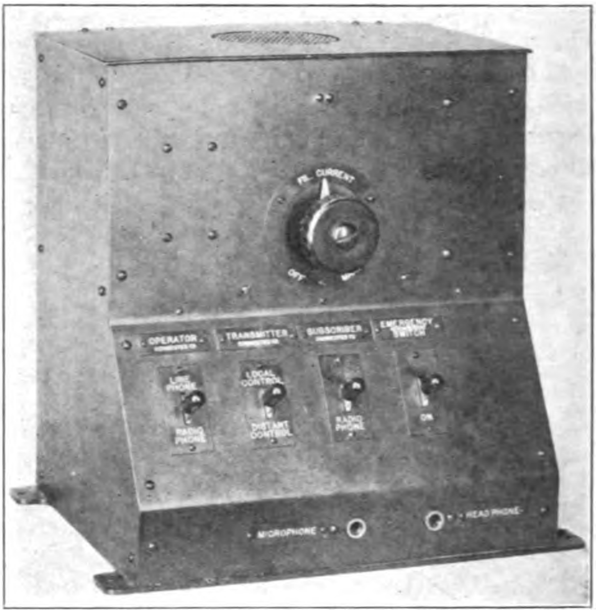

Figure 41A

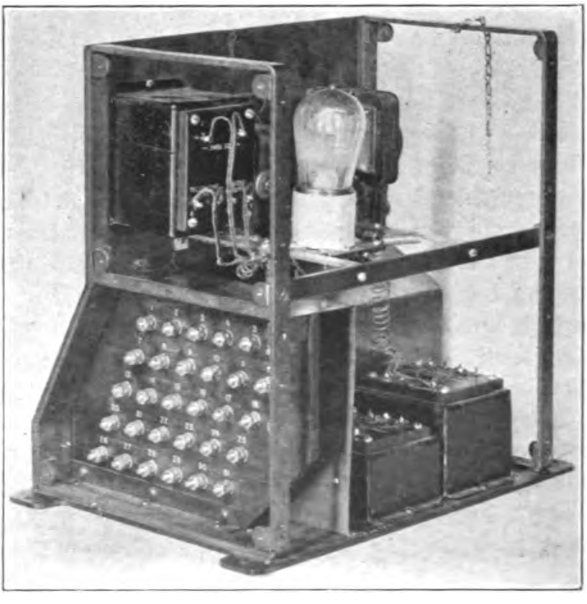

Figure 41B

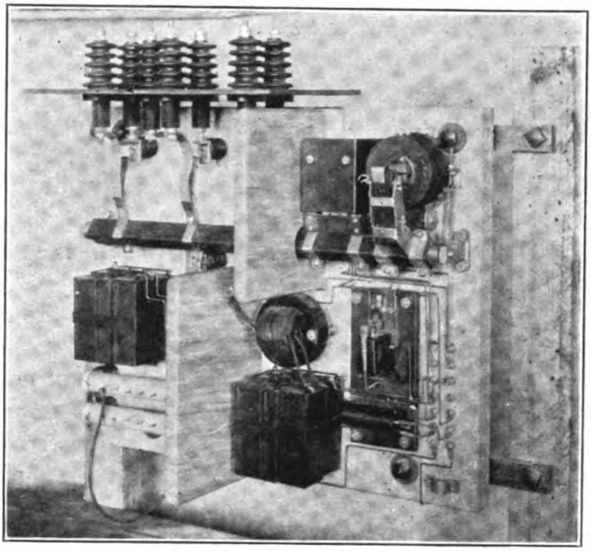

FIGURE 42A

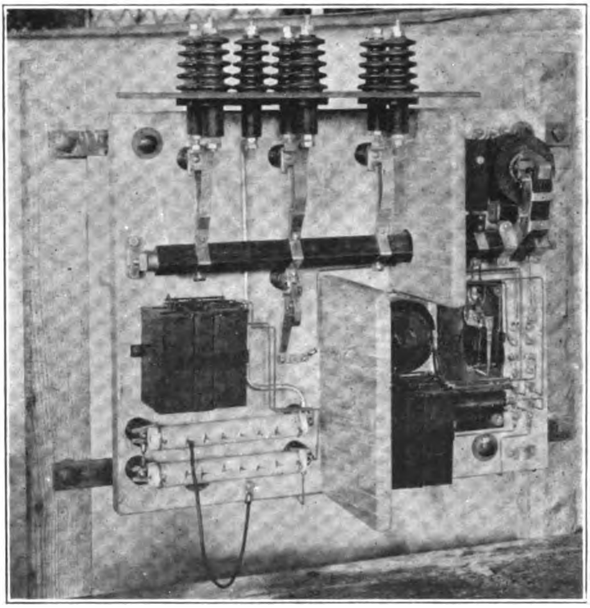

FIGURE 42B

fier input transformer or the secondary winding of the radio receiver output transformer, depending upon the initial position of the shaft for radio reception or transmission. The three contacts at the left close the plate circuit, transfer the antenna from radio receiver to radio transmitter, and close the grid circuit. These contacts close in this order and open in the reverse order. The terminals for the plate, grid and antenna contactors are mounted on insulators which extend 3.5 inches (8.9 cm.) above the relay panel box.

Below the plate, grid, and antenna contactors are mounted resistors and by-pass condensers forming a potentiometer by which power for the plate circuit of the amplifier tube is obtained from the radio transmitter high voltage supply. Marble barriers are placed to the right of the high voltage portion of the relay panel and the box door over this portion may remain closed while the other side is opened, thus protecting the operator while making adjustments or repairs on the low voltage portion of the panel.

The foot switch used at the radio station is of the same design as that supplied for the distant subscriber's station, but instead of connecting a pulse source to the telephone line it merely actuates the position relay on either an upward or downward movement, and is connected in parallel with the emergency send-receive or synchronizing key on the operator's control unit.

Conclusion

This completes a review of some of the tube transmitting equipment now used in the United States Navy. This apparatus, the first of its kind in this country to be manufactured in quantity and placed in an operating service, may be regarded at the present time as an expedient to render service during the development of more suitable equipment. It is keenly realized that more satisfactory, less expensive, and higher power vacuum tubes must be made available, that the sources of power supply must be improved, and that to be wholly practical the radio telephone must be a duplex system on high power as well as low power. Active development is being conducted to the accomplishment of these and other ends.

However, the apparatus herein described does represent the first application to an operating service of the principles and devices known until recently only in the research laboratory. This apparatus in its development has suffered a severe handicap in lack of design experience, but its development has resulted in establishing a measurable amount of this experience.

The highest credit is due the engineers of the Western Electric Company, the General Electric Company, and the Navy Department who have labored untiringly to make this equipment a realization. Their work and its results will be a guide and an inspiration to the accomplishments of the future.

SUMMARY: The Navy Department's policy of pursuing the development of vacuum tube transmitters and the reasons therefor are discussed. There are then outlined the performance requirements for apparatus of this type for Naval use and the considerations involved in its standardization.

There are made some preliminary statements regarding standard equipment, including the discussion of ratings and circuits used. The standard apparatus for measuring antenna characteristics is described in detail. A brief review is given of the tubes used, the reasons for their selection, and some novel points regarding their operation.

Some of the representative standard transmitters are then described, including 5, 150, 300, and 750-1,500 watt equipments. Consideration is also given to several recently developed remote control systems.

SOME IMPROVEMENTS IN THE POULSEN ARC*

Part I

(*A Method for Reducing the Intensity of the Magnetic Field in the Poulsen Arc. Single Voltage Peak Operation. The "Ideal" Arc*)

By

P. O. Pedersen

(Professor in the Royal Technical College, Copenhagen, Denmark)

Introduction

In a series of investigations the author has endeavored to explain the operation of the Poulsen arc, and the main results of these investigations have been published in these Proceedings.[1] The understanding of arc operation thus obtained made it possible to improve the arc in several ways; and a brief description of some of these improvements may possibly be of interest to some readers of the Proceedings of The Institute of Radio Engineers.

The *ignition* voltage of the arc may either be higher or lower than the extinction voltage. In the first case, the arc is actually extinguished once in every period and the arc voltage shows separate extinction and ignition peaks, as shown in reference (a) below, Figures 16a, parts *a–d*. When the ignition voltage is lower than the extinction voltage, or at most equal to it, the arc is not actually extinguished. The arc current in this case momentarily diminishes almost to zero, but not quite, because a "new" arc strikes at the edges of the electrode before the "old" one is completely extinguished. In this case, the arc voltage has only *one* peak in every period. (See reference (a), Figure 16a, part *e*, and reference (b), Figure 1.) We shall, in the following, speak of *one-peak* and *two-peak* operation respectively.

We have, in the previous papers, mainly considered two-peak operation. One-peak operation is, however, the ideal method; and this ideal is obtained thru the improvements to be described in this paper. Two-peak operation has been, up to now, the most stable manner of functioning of the normal Poulsen arc. In order to enable us to understand the difference between one-peak and two-peak operation, we will, therefore, first touch briefly upon those features in the two-peak operation which must be changed in order to obtain stable one-peak operation.

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*Received by the Editor, March 1, 1921.

[1] (a) "On the Poulsen Arc and Its Theory," Proceedings of The Institute of Radio Engineers, volume 5, pages 255-316, 1917.

(b) "Supplementary Note," volume 7, pages 293-297, 1919. Referred to above as (a) and (b). For list of symbols, see reference (a), pages 315, 316

As shown on page 303 of reference (a), the supply voltage V_o is related to the intensity H of the magnetic field in the manner shown diagrammatically in Figure 1.

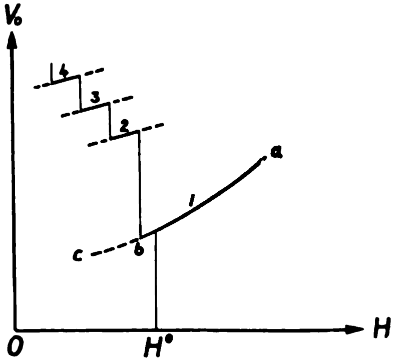

FIGURE 1—Diagrammatic Representation of the Supply Voltage V_0 as a Function of the Field Intensity H. (The Figures on the Curve denote the Number of Arcs to be seen in the Side View)

The first part *ab* of the (H, V_o) curve, corresponding to high field intensities has quite a regular shape, V_0 decreasing with decreasing field intensity. As the efficiency of the arc is inversely proportional to the value of V_o, it is most advantageous to employ as weak a field as possible. On the other hand V_o increases rapidly with decreasing field intensity below the point *b*. Hence, in practice, a value such as H^o a little to the right of the point *b* must be applied.[2] *For the normal Poulsen arc H^o is the most desirable value for the intensity of the magnetic field.*

On the other hand, a reduction of the field intensity below H^o in Figure 1 would, if possible, offer a number of advantages: (1) The reduction of the field intensity is in itself of great advantage in large arcs.[3] (2) The efficiency of the arc would probably increase somewhat, as indicated by the curve *a b c* in Figure 1. (3) In weak fields, the arc would give one-peak operation. *Regular one-peak operation is of advantage since it gives a radio frequency current wave of almost perfectly pure sinusoidal shape, and thus eliminates any harmonics which may be caused by sudden bends in the current curve.* As shown in reference (a), Figure 16a, part *e* such single voltage peak operation has also been obtained in a normally operating arc—the arc starting once in every period from the edges of the electrodes—and with a carefully regulated weak field and the correct distance between the electrodes. Thus regulated, the arc may burn for a long time with only one peak of arc voltage in each period, especially if the electrodes have a suitable shape. But, generally, this operation is not very stable, being likely to change over to the "two-step operation" shown in reference (b), Figure 2, parts *c*, *c′*.

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[2] An explanation of the remarkable shape of the (H, V_0) curve is given in references (a) and (b).

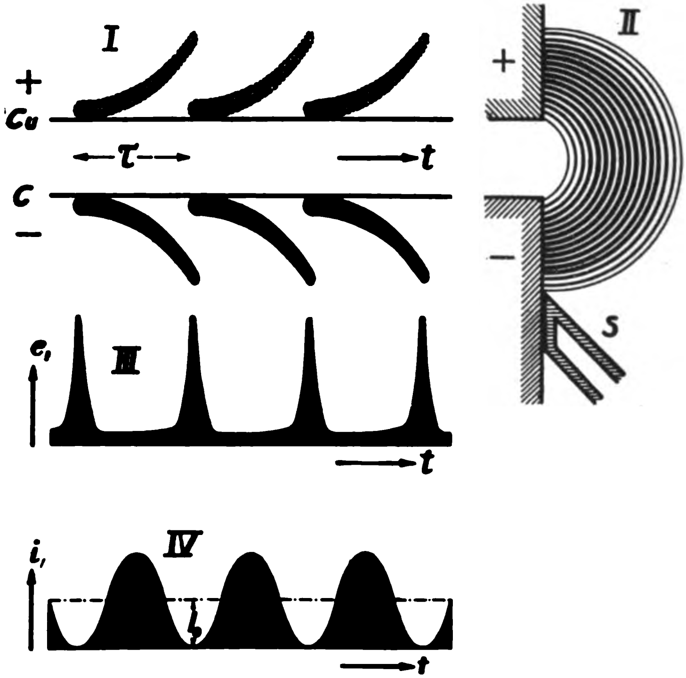

FIGURE 2—Diagrammatic Representation of the Operation of an Arc with Cooling Shoe, *S*

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[3] Valuable information is given concerning the difficulty of obtaining a sufficiently strong magnetic field in large arcs in a paper by L. F. Fuller, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 7, pages 449-497, 1919.

The problem is thus to reduce the field intensity considerably below H^o—or rather below the point b in Figure 1—and at the same time induce the arc to operate regularly with one voltage peak. This may be done, and quite easily, by employing a water-cooled copper shoe (cooling shoe) on the cathode in order to limit the travel of the arc along the cathode. (See Figures 2 and 3; where C is the cathode (carbon) and Cu the water-cooled anode (copper).

As an arc can exist only when the cathode crater is in an incandescent state, *such a cooling shoe will effectively prevent the arc from traveling further out along the cathode even if the field is so weak that the arc would do so without the cooling shoe.* At the end of the period the arc—having reached the edge of the cooling shoe—must, therefore, necessarily be extinguished and simultaneously a new one start at the edges of the electrodes.

This view was fully confirmed by the results of our experiments with a cooling shoe,[4] of which a few are tabulated below.

TABLE 1

Wave Length = 9,800m.
R = about 5 ohms
I = Radio Frequency Current
$L = 13 \times 10^5$ cm.
V_o = Arc Voltage
C = 18,650 cm.
I_o = Supply Current
I_m = Current thru Magnet Coils

V_o	I_o	I	I_m	H (Gausses)	Cooling Shoe	Form of Field
372	71	50	0.9	1,500	with shoe	homogeneous
376	71	50	2.8	2,200	without shoe	

The result tabulated above is only one of a long series of measurements, but is characteristic of the results obtained thruout.

In order further to test the correctness of this explanation of the operation of the arc with a cooling shoe, we have taken a number of Gehrcke-tube oscillograms of the arc voltage in an arc with cooling shoe. *They all show a regular one-step and one-peak operation of the arc.*

Another advantage is that the arc burns even more steadily with the cooling shoe than without it. This is quite natural as the arc now travels over exactly the same distance along the electrode during every period, the crater path being sharply limited by the cooling shoe where the carbon burns away along quite a steep surface, as is shown in *a* of Figure 3. Without the cooling shoe the carbon burns away as shown by the dotted line *a-b*. Without the shoe, the arc may in this case accidentally travel further out during one period than during another, which will cause a corresponding small variation in the wave length.

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[4] The cathode cooling shoe is patented in various countries.

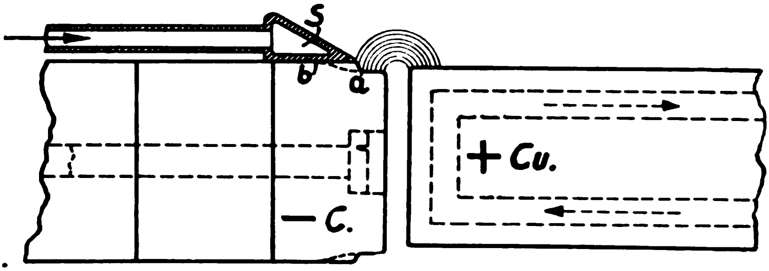
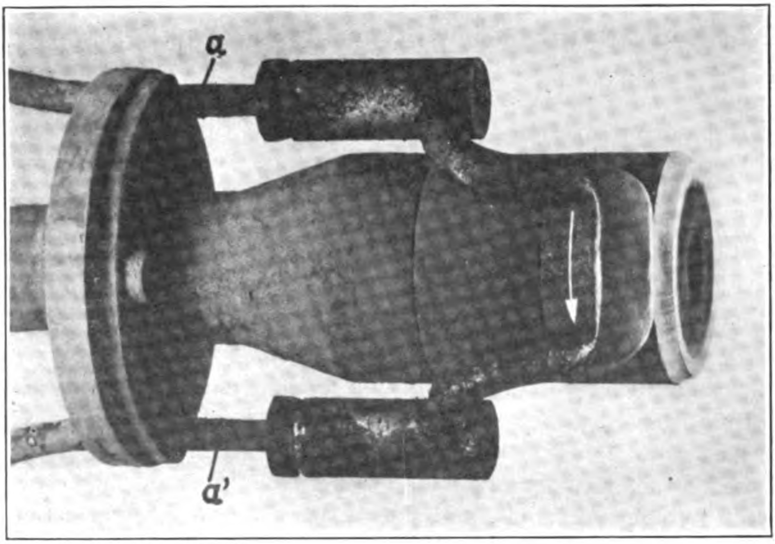


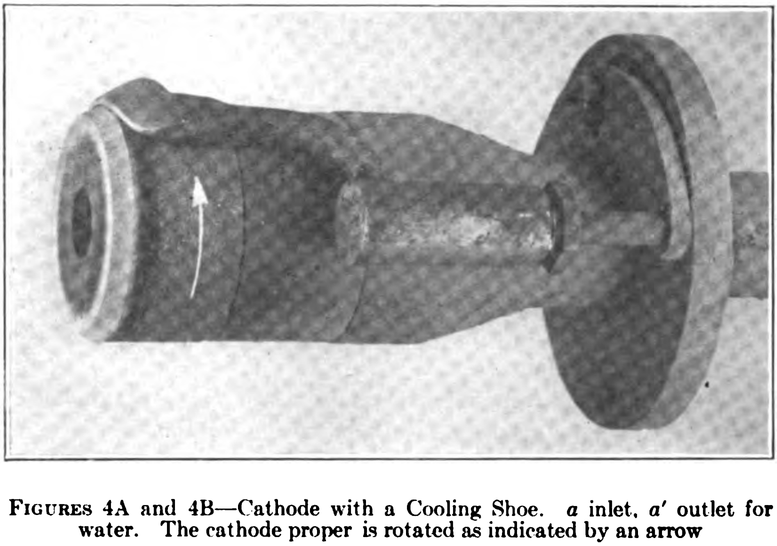
FIGURE 3—Cathode with Water-cooled Shoe *S*. The Cathode is Slowly Rotated

There is no trouble at all in attaching and maintaining the cooling shoe in operation. The angle which the surface facing the arc makes with the axis of the electrodes is of some importance, and the distance from the edge of the electrode to the edge of the shoe should be closely adjusted. The value of this distance depends on the wave length and on the value of the current. The shoe must not be moved toward the cathode edge after the arc has been burning for some time, since there is danger that the arc will then burn underneath the tip of the shoe and melt it.

The arc from a cathode provided with a shoe is extremely easy to start and to adjust. The wear on the carbon is very slight and very regular, and the same carbon may, therefore, be used for a very long time, especially if the relative height of the cathode and the anode can be adjusted according to the wear on the carbon. Figure 4A and 4B are two photographs of a cathode provided with a cooling shoe. This form of shoe has served very well.

Some peculiarities noted during the experiments on cooling shoes may be mentioned. When the carbon has burned with the shoe for at least one revolution, the shoe may be temporarily





FIGURES 4A and 4B—Cathode with a Cooling Shoe. *a* inlet, *a'* outlet for water. The cathode proper is rotated as indicated by an arrow

removed without appreciably altering the working of the arc; but after a little while the arc becomes unsteady and the field intensity must be increased. The reason for this is quite evident. As long as the carbon retains its steep profile at *a*, the arc will, when once started, have a tendency to burn in the same way without the shoe as with the shoe. But as soon as the carbon profile approaches the line *a b*, the arc changes over to working in two or three steps. A continuous operation under the improved conditions is possible only with the use of the shoe. Turning down the carbon to the profile shown in heavy outline in Figure 3, and then using it without a shoe has also been tried, but no practically useful results were obtained in this way.

In order to illustrate the difference between one-peak and two-peak operation, we have in Figure 5 shown the arc current and the arc voltage in the two cases, part A representing two-peak and part B one-peak operation.

A very important advantage of the one-peak operation, as mentioned before, is the elimination of the sudden bends in the current curve at the points where the arc is extinguished and re-ignited with the two-peak operation. These sudden bends indicate the existence of some of the higher harmonics in the radio frequency current, and they may cause free oscillations in the antenna and other nearby conductors. The radiations caused by these harmonics and free oscillations may cause interference at neighboring receiving stations when conditions are unfavorable. Of course, all these effects may, if necessary, be eliminated by methods similar to those used for the same purpose in connection with large thermionic tube generators and in connection with mechanical alternators with static frequency changers or they may be eliminated in other ways.[5] But it is clearly simpler if the current curve is without any bends at all, and with regular one-peak operation, the current curve is almost exactly a pure sine curve and the above-mentioned disturbances are reduced to an absolute minimum. Probably no other radio frequency generator is able to give so smooth a sine curve.

An arc operating regularly with one-step and one-peak functioning may properly be called an ideally operating Poulsen arc.

No great increase in the efficiency of the arc was directly obtained by the use of the cooling shoe. Other means, however, have been found which substantially increase this efficiency, and these means will be described in a later paper.

In conclusion I desire to acknowledge my indebtedness to Mr. J. P. Christensen for the excellent help he has given me in this work.

Royal Technical College, Copenhagen, February, 1921.

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[5] F. A. Kolster, "Re-enforced Harmonics in High Power Arc Transmitters," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 7, page 648, 1919.

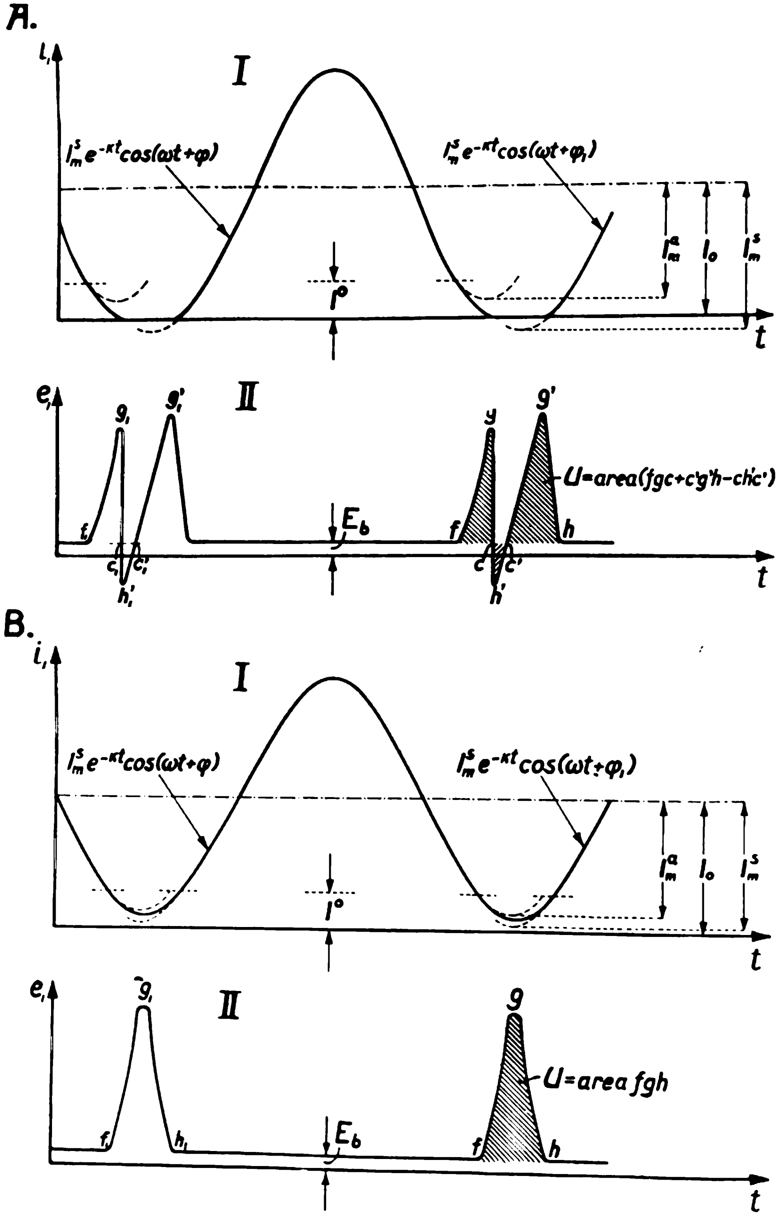

FIGURE 5—Diagrammatic Representation of the Current and Voltage Curves for (A) Two-peak and (B) One-peak Operation

SUMMARY: The operation of the Poulsen Arc with only one voltage peak per period is shown to be desirable in that it permits the use of weaker magnetic fields across the arc and gives a nearly sinusoidal radio frequency current. The obtaining of one-peak operation by a suitably shaped and situated cathode cooling shoe is described and explained.

DIGEST OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued June 21, 1921—August 16, 1921

By

John B. Brady

(Patent Lawyer, Ouray Building, Washington, D. C.)

The object of this section in the Proceedings of The Institute of Radio Engineers is to make available in convenient form for research engineers and others interested, brief information on radio patents which are issued each week by the Patent Office. The rapid development in this art emphasizes the importance of radio research engineers being familiar with patent literature to eliminate, as far as possible, the duplication of effort in research. It is not the purpose of this section to explain radio inventions fully, but merely to indicate the general nature of the patents in order that those of particular interest to individuals concerned with certain problems may be selected and complete copies of the patents obtained for study. Copies of the patents may be secured at ten cents each by communicating with the Commissioner of Patents, Washington, D. C.

1,381,089—Harold H. Beverage, Schenectady, New York, filed April 10, 1920, issued June 7, 1921. Assigned to General Electric Company.

Radio-Receiving System, including a horizontal and aperiodic antenna extending in a direction parallel to the direction of transmission of the signals to be received. The antenna is constructed with distributed capacity, inductance, and resistance of such values that the currents produced therein by the desired signals increase progressively from the end of the antenna nearest the transmitting station at *A* in Figure 1 to a maximum at the farthest end from the transmitting station at which the receiver is connected in Figure 1.

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*Received by the Editor, August 31, 1921. While great care has been taken in the preparation of these Digests, The Institute of Radio Engineers assumes no responsibility for their correctness or completeness, or for possible omissions of particular patents.—Editor.

Fig. 1

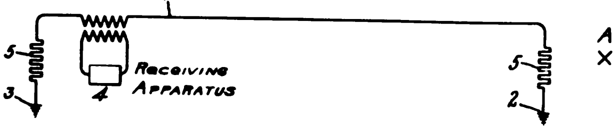


Fig. 2

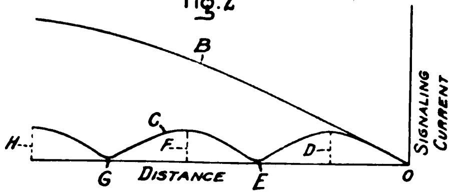
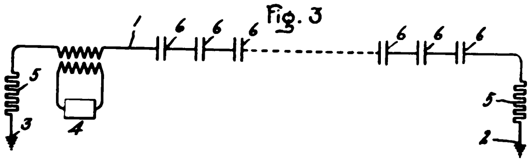


Fig. 3



Number 1,381,089—Radio Receiving System

1,382,177—William Dubilier and Philip Dubilier, New York, N. Y., filed July 10, 1916, issued June 21, 1921. Assigned to Sperry Gyroscope Company.

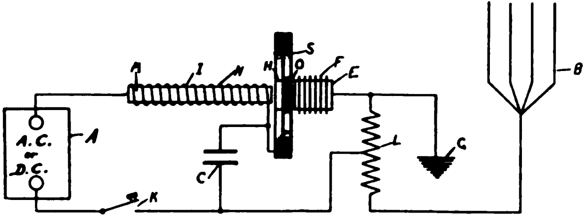


Fig. 1.

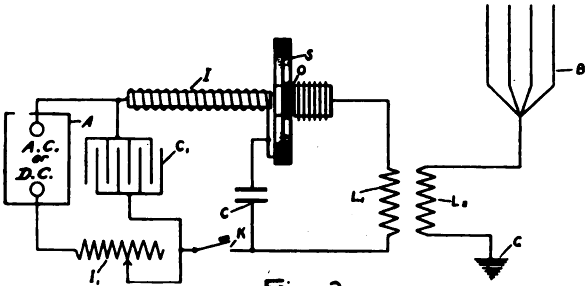
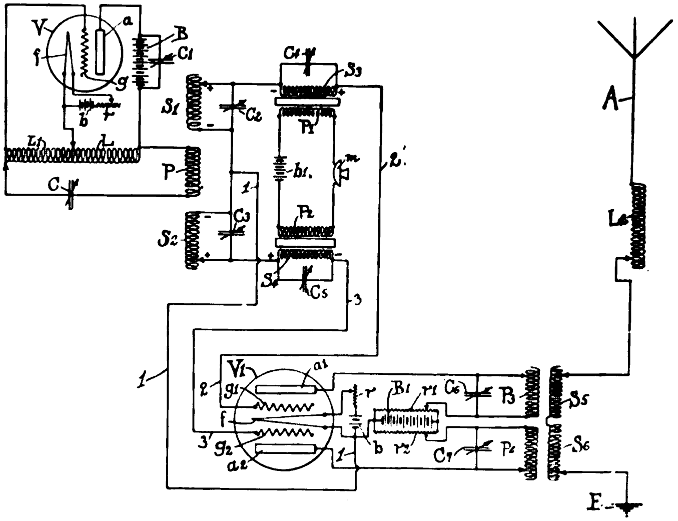


Fig. 2.

Number 1,382,177—Radio Signaling Apparatus

Radio Signaling Apparatus, comprising a form of transmitting equipment wherein radio frequency oscillations are produced in a highly quenched circuit closely coupled to a radiating circuit. The oscillating circuit comprises a make and break or vibratory spark gap controlled by a power source of alternating or direct current, with the radiating oscillating circuit connected across the gap and closely coupled with the antenna system.

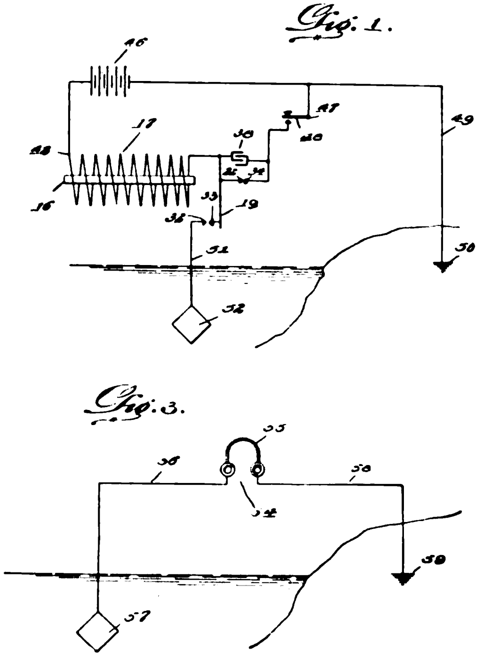
1,382,206—David G. McCaa, Lancaster, Pennsylvania, filed January 19, 1920, issued June 21, 1921. Assigned (one-half) to Cornelius D. Ehret, Mount Airy, Philadelphia, Pennsylvania.



Number 1,382,206—Transmitting Apparatus

Transmitting Apparatus, for radio telephony in which the radio frequency energy is not present in the antenna and ground system until the microphone is operated. The carrier frequency oscillations are generated by vacuum tube *V* and controlled by a microphone such that instantly the voice or sound waves cease at the microphone, the radio frequency energy ceases in the antenna system; and, similarly, instantly sound waves or speech is initiated and continued at the microphone, oscillations are present in the antenna system and vary in accordance with the speech.

1,382,590—William G. Ziegler, Chicago, Illinois, filed January 3, 1920, issued June 21, 1921.



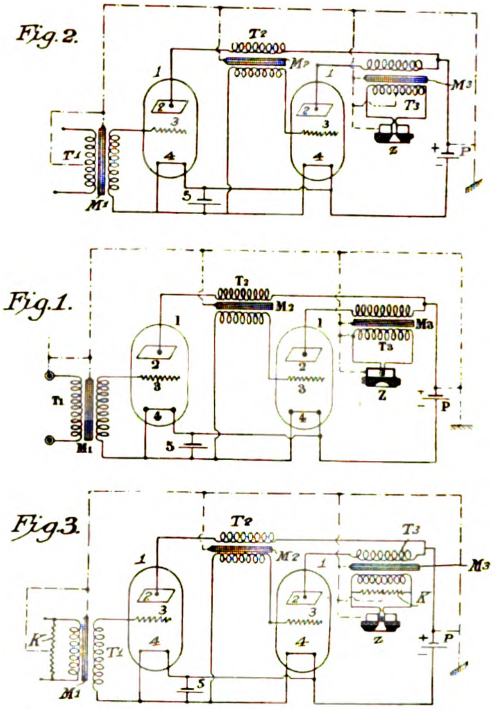
Number 1,382,590—Submarine Wireless System

Submarine Wireless System, operating at low frequencies. The patent discloses a particular form of transmitting and receiving apparatus.

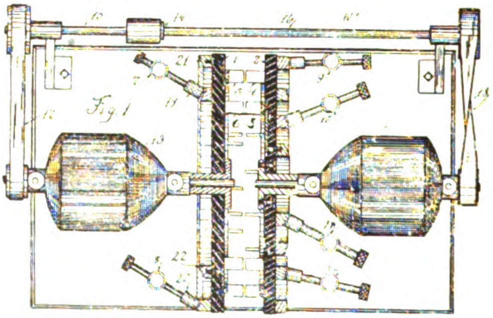
1,382, 738—Marius C. A. Latour, Paris, France, filed June 8, 1918, issued June 28, 1921.

Amplifying Apparatus, constructed to eliminate objectionable noises due to the setting up of oscillations. The potential of the frame or casing of the telephone head-piece, and the operator, and the frames or cores of the transformers and of the primary winding of the first transformer are maintained at a potential equal to that of the earth.

1,382,786—August J. Kloneck, New York, N. Y., filed June 3, 1916, issued June 28, 1921.



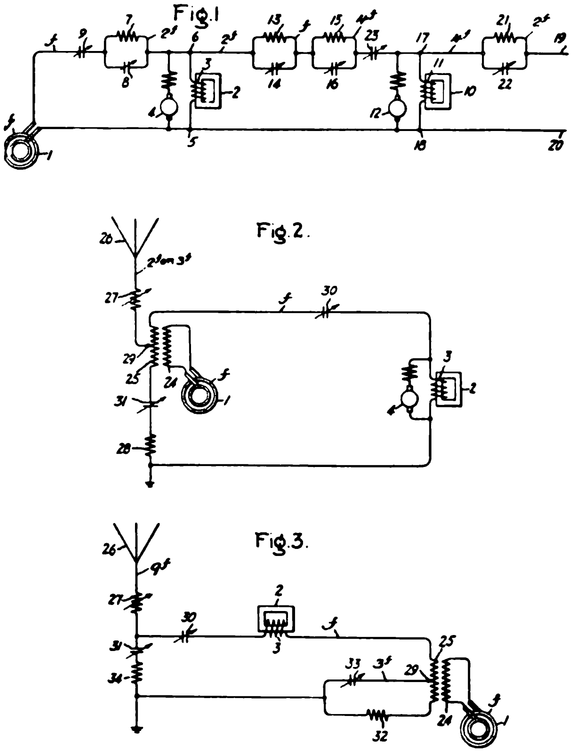
NUMBER 1,382,738—Amplifying Apparatus



NUMBER 1,382,786—Rotary Spark-Gap

ROTARY SPARK-GAP, comprising a pair of rotors holding electrodes formed in sections which are brought adjacent to each other in operation. The electrodes form spark gaps giving the desired number of current interruptions. The rotors are driven in opposite directions.

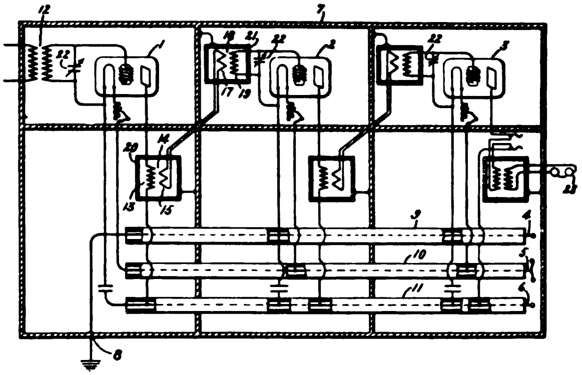
1,382,877—Ernst F. W. Alexanderson, Schenectady, New York, filed October 6, 1916, issued June 28, 1921. Assigned to General Electric Company.



Number 1,382,877—Means for Frequency Transformations

Means for Frequency Transformations, wherein is employed an iron core inductance thru which the current from the alternator passes and operates in such a way that the core becomes saturated and thereby produces a distorted voltage wave at its terminals. The circuit which includes this inductance and the source of current of fundamental frequency is preferably resonant to the fundamental frequency and is so adjusted that it offers a relatively very high impedance to the flow of current of the harmonic frequency which is to be utilized. The distorted voltage wave produced is applied to a second circuit which is resonant to the desired harmonic frequency. This second circuit may also be so adjusted that it offers a high impedance to current of the fundamental frequency or other means may be employed for preventing current of the fundamental frequency from flowing in the second circuit, and vice versa. If it is desired to produce a current having a frequency equal to an even harmonic of the fundamental, the iron core inductance may be saturated by means of a direct current. If an odd harmonic is to be utilized, this will not be necessary altho in some cases a small amount of direct current may be utilized to assist in tuning.

1,382,914—Charles A. Hoxie, Schenectady, New York, filed May 10, 1920, issued June 28, 1921. Assigned to General Electric Company.



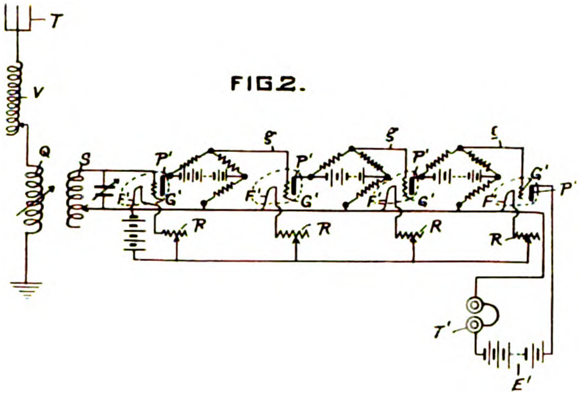
Number 1,382,914—Amplifying System

Amplifying System, designed to avoid undesirable production of oscillatory currents in cascade amplification and to be highly selective to a particular frequency without producing an appreciable amplification of currents of other frequencies. The different stages of the amplifier have substantially no electrostatic coupling and are shielded to prevent entirely any feedback action from an output circuit to the input circuit of a preceding stage.

1,383,275—Samuel E. Adair, New York, N. Y., filed August 14, 1919, issued July 5, 1921. Assigned to International Radio Telegraph Company.

Amplifier, designed to be free from oscillating disturbances which result in producing "howls," and also free from paralysis due to the production of negative charges on the grids of the tubes. In this amplifier the vacuum tubes in the several stages are connected in one branch of a series of Wheatstone bridge circuits.

FIG2.



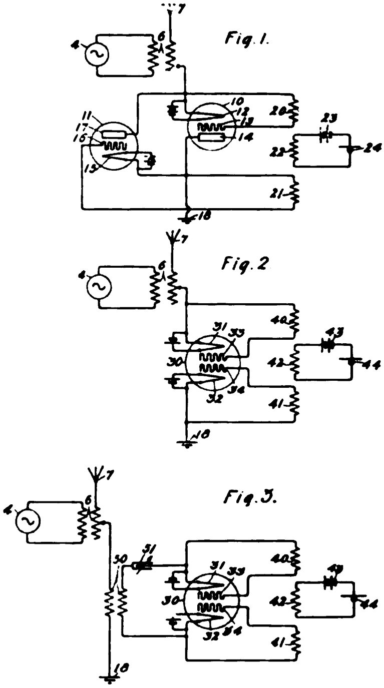
NUMBER 1,383,275—Amplifier

1,383,807—Raymond A. Heising, East Orange, New Jersey, filed September 21, 1915, issued July 5, 1921. Assigned to Western Electric Company.

POWER MODULATION FOR RADIO TRANSMISSION, wherein only a small current passes directly thru the telephone transmitter or other signaling device. The modulation of the total radio frequency power is obtained by varying the impedance of a vacuum tube placed in an antenna circuit. In order to permit the passage of both halves of the radio frequency oscillations, the system is made symmetrical by using two vacuum tube impedances, Figure 1, suitably connected or by using a single vacuum tube impedance containing additional elements, Figures 2 and 3, which render the circuit symmetrical.

1,384,014—Reginald A. Fessenden, Brookline, Massachusetts, filed January 14, 1918, issued July 5, 1921. Assigned to Submarine Signal Company.

METHOD AND APPARATUS FOR SIGNALING AND OTHERWISE UTILIZING RADIANT IMPULSES, in which a tetrahedron collector, Figures 1, 2, and 3, having three joining faces at right angles to each other and another surface in proximity to the tetrahedron is employed whereby the incidence of radiant energy on the tetrahedron may be determined. The system employs light waves, heat waves, ultra-violet waves, X-rays, Hertzian waves, or sound waves.



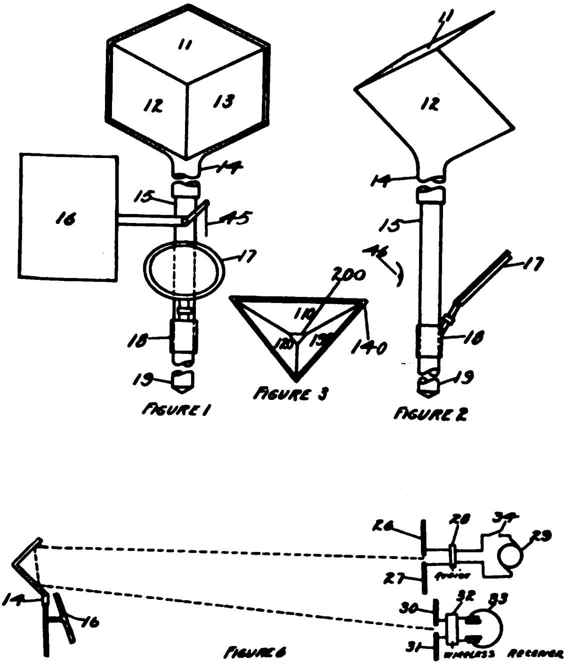
Number 1,383,807—Power Modulation for Radio Transmission

1,384,108—Roy A. Weagant, Roselle Park, New Jersey, filed April 9, 1914, issued July 12, 1921. Assigned to Radio Corporation of America.

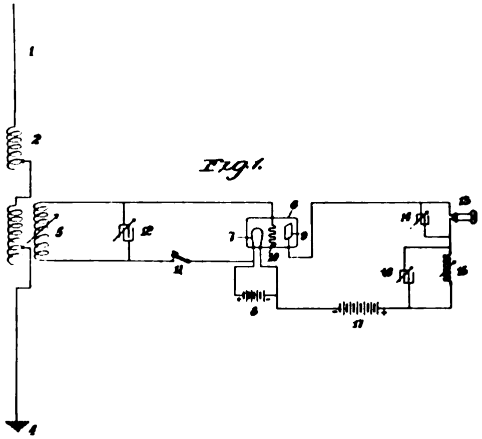
Means for Generating Electrical Oscillations, comprising a vacuum tube oscillator circuit in which an adjustable non-inductive resistance is connected between two of the electrode members of the vacuum tube.

1,384,523—Athelstan Argyle Hall, London, England, filed November 1, 1919, issued July 12, 1921.

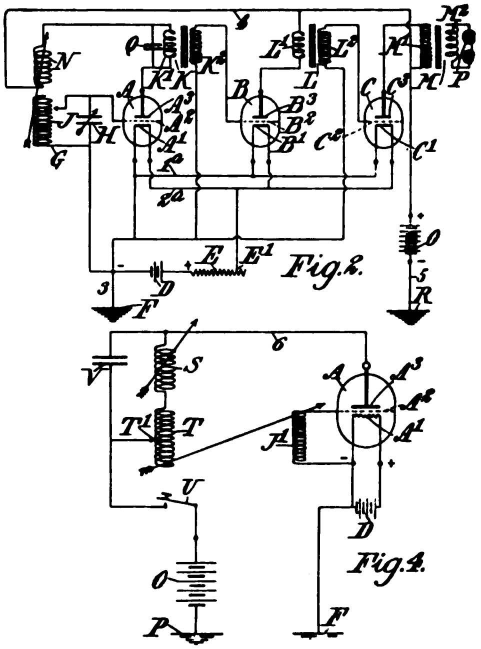
"Wireless" Signaling Apparatus, comprising an oscillating vacuum tube transmitter wherein the oscillatory circuit is completed thru a portion of the earth. The portion of the earth between the connections of the oscillating circuit is intended to constitute in effect the receiving or transmitting medium of the system.



Number 1,384,014—Method and Apparatus for Signaling and Otherwise Utilizing Radiant Impulses



Number 1,384,108—Means for Generating Electrical Oscillations

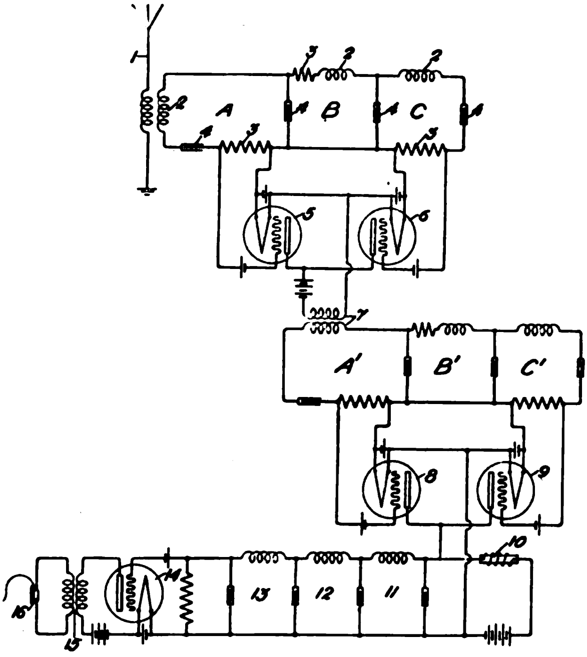


NUMBER 1,384,523—"Wireless" Signaling Apparatus

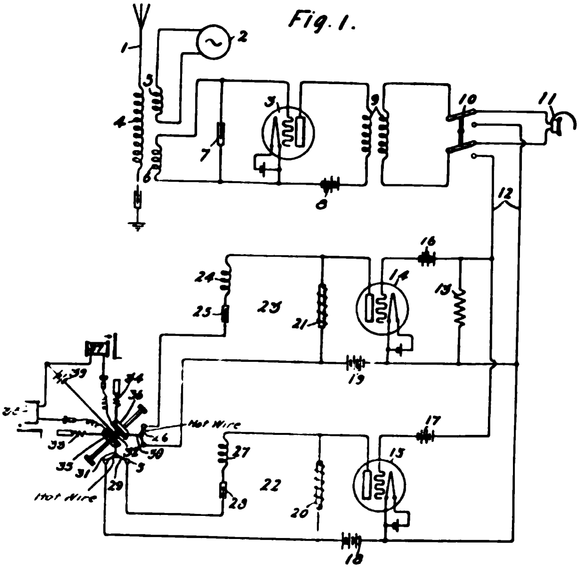
1,385,090—John Mills, Wyoming, New Jersey, filed February 19, 1916, issued July 19, 1921. Assigned to Western Electric Company.

RADIO RECEIVING SYSTEM, including an electrical network connection which discriminates between the effects of impulsive and of periodic excitation of the receiver. The network reduces the effect of the impulsive excitation or static disturbances, while permitting the passage of the periodic excitation or the oscillations produced by a sustained voltage received from the transmitter. This is accomplished by making use of the fact that the free oscillations in the various sections of a recurrent network, produced by such an impulsive excitation as a static disturbance, for example, maintain certain invariable phase and amplitude relations for each mode of oscillation, irrespective of the damping of the network, while the forced oscillations, due to a signal to be received, are attenuated and altered in phase in passing along the network.

1,385,091—John Mills, Wyoming, New Jersey, filed September 25, 1916, issued July 19, 1921. Assigned to Western Electric Company.



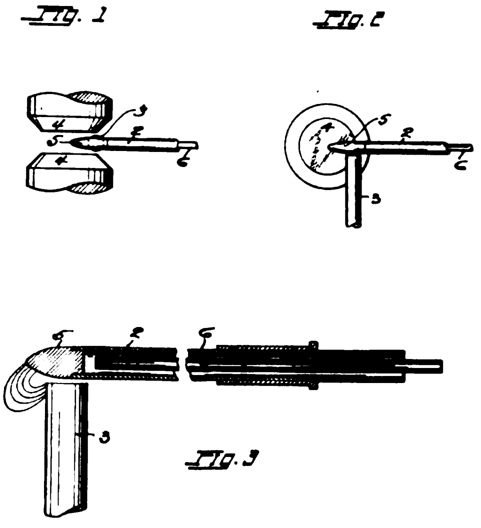
Number 1,385,090—Radio Receiving System



Number 1,385,091—Signaling

SIGNALING, or more particularly a radio receiving apparatus for the elimination of strays. The principle of this circuit is based on the balancing of the energy in two different circuits. As a stray excites the circuits equally, the energies may be neutralized. It is immaterial what the instantaneous values of the currents may be as the energy responsive devices controlling the signaling instrument integrate the energy received and do not respond to the instantaneous current values. Signals received on a desired single frequency, however, excite the two circuits unequally and cause the desired operation of the receiving instrument.

1,385,121—Harold F. Elliott, Palo Alto, California, filed March 23, 1920, issued July 19, 1921. Assigned to Augustus Taylor.



NUMBER 1,385,121—Arc Radio Oscillation Generator

ARC RADIO OSCILLATION GENERATOR, having in an arc chamber a metallic anode with a cylindro-conoidal tip and a cathode disposed at a right angle to the axis of the anode with the cathode tip positioned back from the end of the anode tip. The patentee points out that in the previous type of arc there was considerable tendency for the arc to wabble and wander around on the anode with occasional jumping to the magnetic field pole tips. This tendency of the arc to jump to the pole tips has sometimes been overcome by reducing the voltage across the arc, but which consequently reduced the power output of the generator. In accordance with the present invention, the arc flame is guided by reason of the shape of the anode which produces steadier operation of the generator and the arc does not wabble or jump to the magnet poles, so that a higher voltage may be impressed on the arc, or for a given voltage the magnet pole tips may be placed closer together, reducing the magnetic air gap and permitting the use of smaller magnet coils.

1,385,379—Frank Kratz, Stuttgart, Germany, filed January 26, 1917, issued July 26, 1921. Assigned to American Bosch Magneto Corporation.

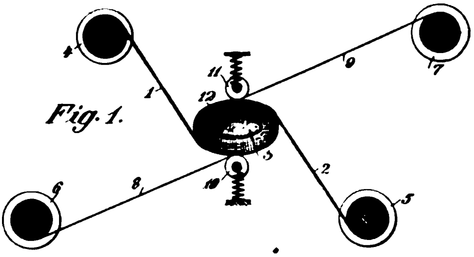


Fig. 1.

Number 1,385,379—Electrical Condenser and Method of Making it

Electrical Condenser and Method of Making It. The condenser is constructed upon an oval core with alternate bands of foil and dielectric wound thereon, the individual bands having laterally projecting edge portions lying flat against the opposite sides of the condenser to form side terminals.

1,385,657—Louis Bell and Norman Marshall, West Newton, Massachusetts, filed March 4, 1918, issued July 26, 1921.

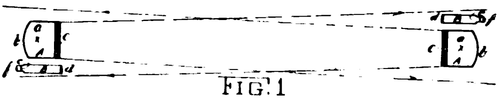
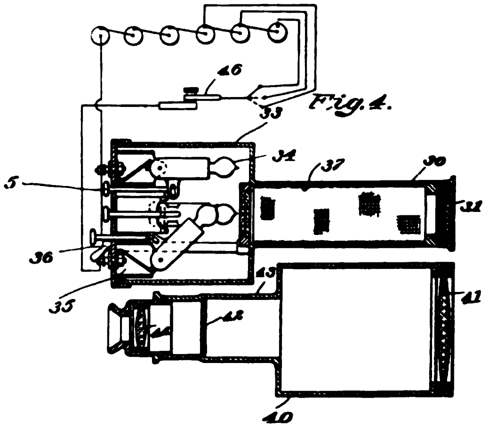


FIG. 1

Number 1,385,657—Method of and Apparatus for Utilization of Observable Radiations

Method of and Apparatus for Utilization of Radiations. Signaling is conducted by use of invisible light rays by forming a directive beam of rays between 400 $\mu\mu$ and 350 $\mu\mu$ wave length and by collecting the rays for observation on a fluorescent medium.

1,385,696—Norman Marshall and Louis Bell, West Newton, Massachusetts, filed February 1, 1919, issued July 26, 1921.



NUMBER 1,385,696—Method and Apparatus for Utilization of Observable Radiations

METHOD AND APPARATUS FOR UTILIZATION OF OBSERVABLE RADIATIONS. A combined transmitting and receiving apparatus is provided for communication by light rays comprising at the receiver an observing objective lens and an eye piece and fluorescent medium acted upon by invisible rays; and, at the transmitter, a projector of rays.

1,385,818—Clair L. Farrand, Elizabeth, New Jersey, filed June 14, 1919, issued July 26, 1921. Assigned to Radio Corporation of America.

RADIO TRANSMITTER, employing a vacuum tube arranged with a plurality of external control members outside of the tube connected in separate circuits. Oscillations are produced in the several circuits and energize the antenna system.

1,385,873—Albert W. Hull, Schenectady, New York, filed June 5, 1916, issued July 26, 1921. Assigned to General Electric Company.

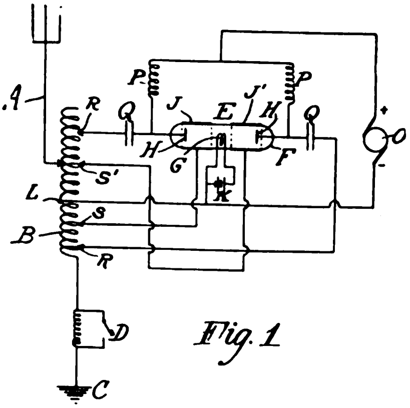


Fig. 1

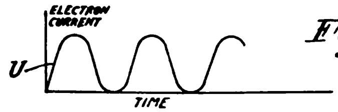
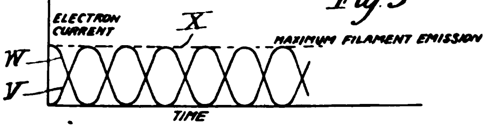


Fig. 2

Fig. 3

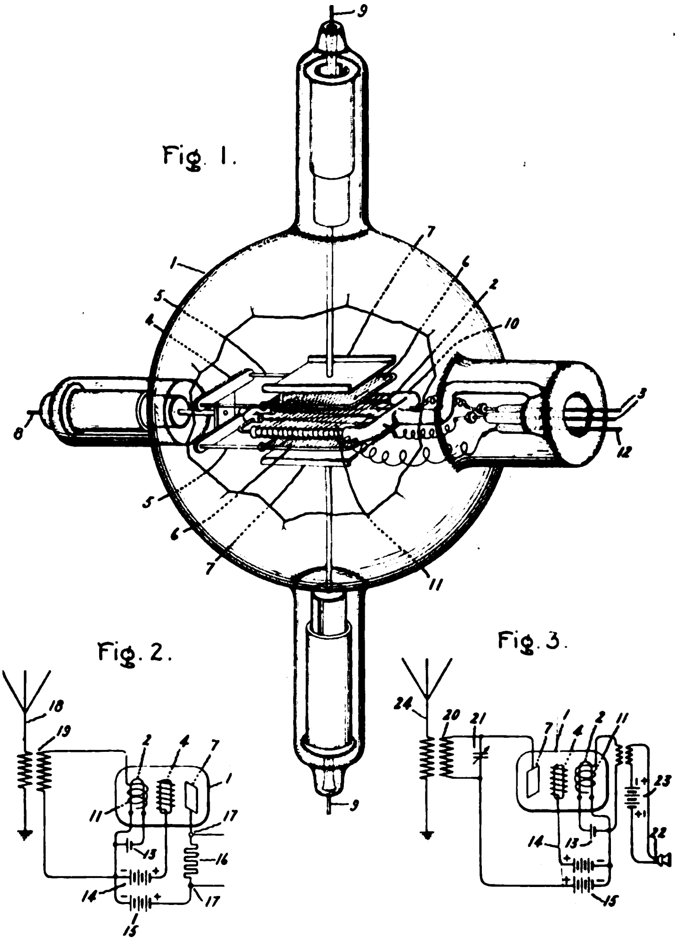


NUMBER 1,385,818—Radio-Transmitter

ELECTRON-DISCHARGE APPARATUS, in which a charge-controlling member in proximity to the cathode is provided and by varying the potential between this member and the cathode, the effective emission of primary electrons is varied, that is, the number of primary electrons which will reach the co-operating electrode is varied. When this is done the number of secondary electrons produced and the negative resistance of the device are also varied and the current in an external circuit between the cathode and the co-operating electrode is varied accordingly.

1,386,830—Ernst F. W. Alexanderson, Schenectady, New York, filed August 5, 1915, issued August 9, 1921. Assigned to General Electric Company.

METHOD OF AND APPARATUS FOR PRODUCING AND DISTRIBUTING ELECTRIC-CURRENT WAVES OF RADIO FREQUENCY, on a current wave which is the equivalent of two electric current waves of different frequencies and of substantially constant amplitudes. The circuits shown in Figures 8 and 9 produce the desired component waves which are shown diagrammatically in Figure 7. The waves *B* and *C* represent the two electric current waves of different frequencies and of constant amplitudes which it is desired to produce. When combined, the waves *B* and *C* produce the wave *A*, which may be resolved into the two waves *B* and *C*.



NUMBER 1,385,873—Electron-Discharge Apparatus

Fig 7

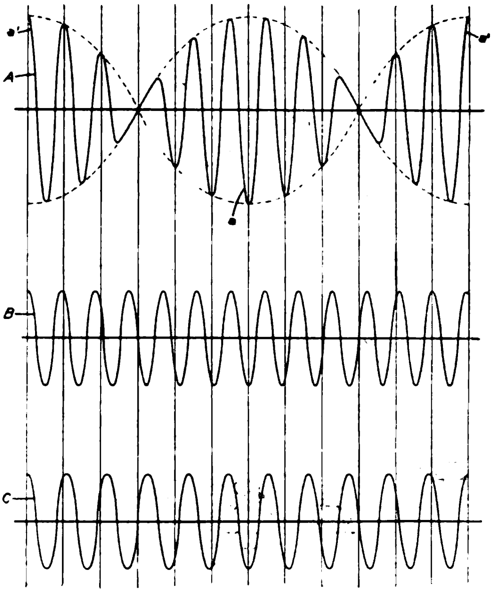


Fig. 8

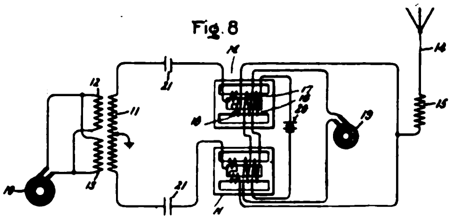
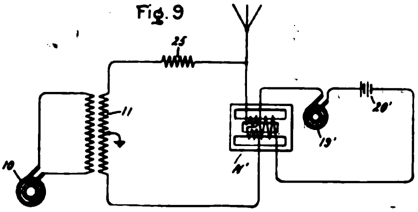
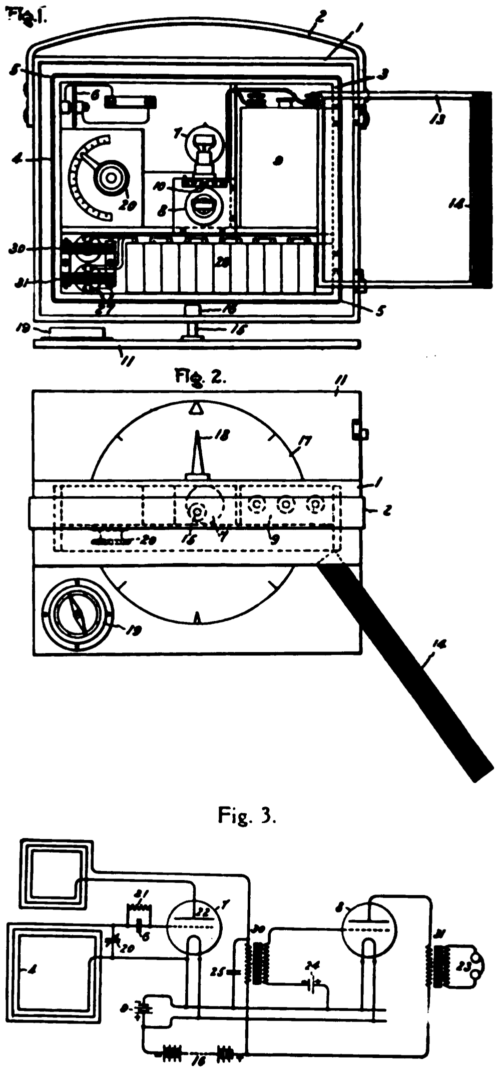


Fig. 9



Number 1,386,830—Method of and Apparatus for Producing and Distributing Electric Current Waves of Radio Frequency

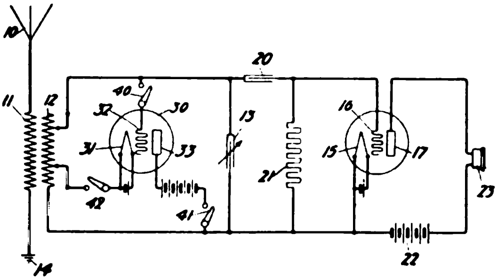
1,386,840—Reginald Charles Clinker, Rugby, England, filed November 29, 1919, issued August 9, 1921. Assigned to General Electric Company.



Number 1,386,840—Radio Signaling System

Radio Signaling System, comprising a readily portable receiving apparatus. The equipment is made compact by providing a coil antenna disposed on a frame with the receiving apparatus carried within the frame, Figures 1 and 2. The complete equipment is mounted in a casing which may be readily transported from place to place. The wiring of the apparatus is shown in Figure 3.

1,387,262—Ralph V. L. Hartley, East Orange, New Jersey, filed September 30, 1915, issued August 9, 1921. Assigned to Western Electric Company.



NUMBER 1,387,262—Receiving Apparatus for Wave Signaling

RECEIVING APPARATUS FOR WAVE SIGNALING, which may be readily changed to receive telephonic and telegraphic signals, either with or without the heterodyne. A local generator at the receiver may be cut in or removed from the circuit to permit reception by means of the heterodyne or by straight rectification and amplification of the signals.

1,387,736—James Harris Rogers, Hyattsville, Maryland, filed May 2, 1917, issued August 16, 1921.

Fig. 1

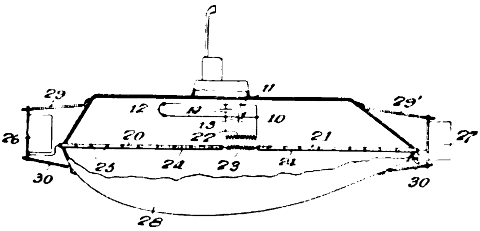
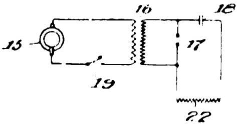


Fig. 2.

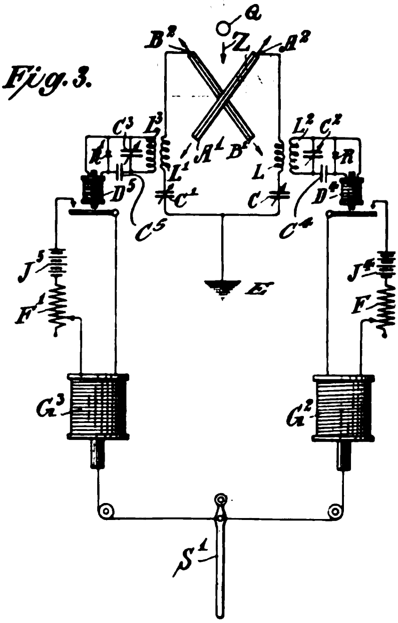


NUMBER 1,387,736—Radio Signaling System

RADIO SIGNALING SYSTEM, for operation aboard vessels. An antenna is employed comprising horizontal wires disposed entirely within the metallic hull of the vessel with a metallic screen inclosing the antennas thruout their length.

1,387,850—John Hays Hammond, Jr., Gloucester, Massachusetts, filed June 7, 1912, renewed January 18, 1921, issued August 16, 1921.

Fig. 3.



NUMBER 1,387,850—System of Radio Directive Control

SYSTEM OF RADIO DIRECTIVE CONTROL, in which the movements of boats, aircraft, or vehicles may be controlled and guided in the direction of a transmitting station. Figure 3 is representative of the system wherein two antennas connected in separate control circuits simultaneously receive energy from a distant transmitter and operate a steering mechanism. The operation is such that the antennas are maintained by the steering mechanism in a position with respect to the distant transmitter to receive equal amounts of energy in the respective circuits.

1,387,986—Albert W. Hull, Schenectady, New York, filed March 10, 1917, issued August 16, 1921. Assigned to General Electric Company.

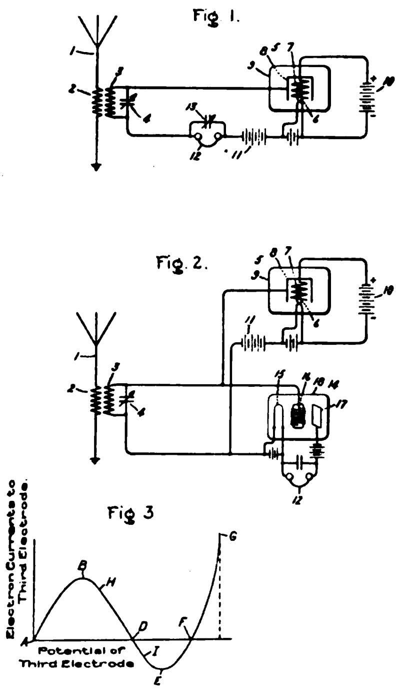


Fig 1.
1
2
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4
5
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8
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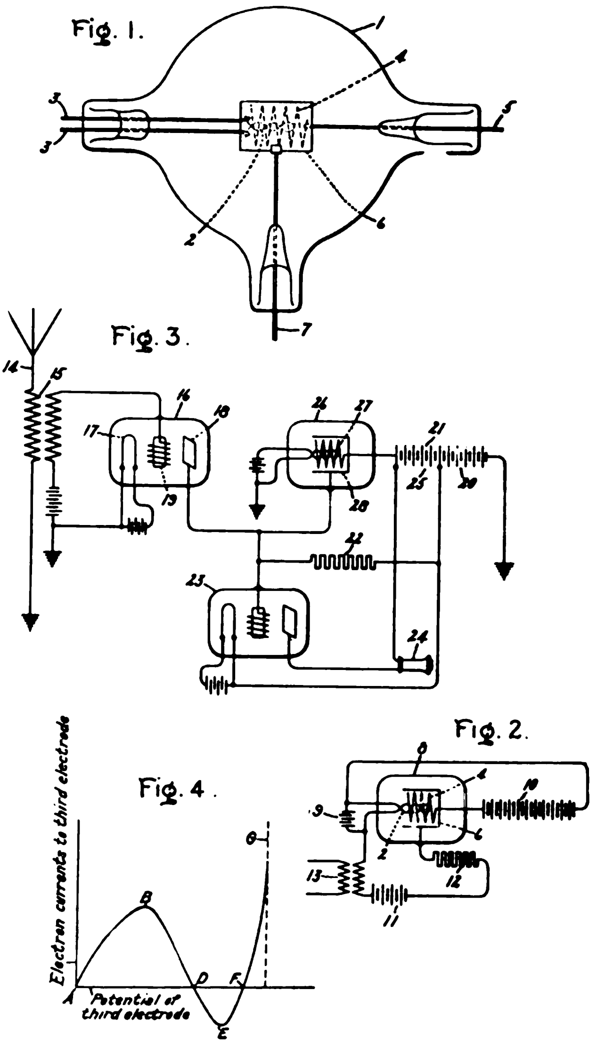
11
12
13
Fig. 2.
14
15
16
17
18
Fig 3
Electron Currents to Third Electrode
Potential of Third Electrode
A
B
H
D
F
G
I
E

NUMBER 1,387,986—Radio Receiving System

RADIO RECEIVING SYSTEM, employing a negative resistance device connected to the radio frequency receiving circuit for reducing the damping thereof. The negative resistance device is connected to the oscillating circuit in such a way as to compensate for the positive resistance of the circuit reducing the damping factor and increasing the maximum possible amplification of the oscillations in the circuit.

1,387,984—Albert W. Hull, Schenectady, New York, filed August 30, 1915, issued August 16, 1921. Assigned to General Electric Company.

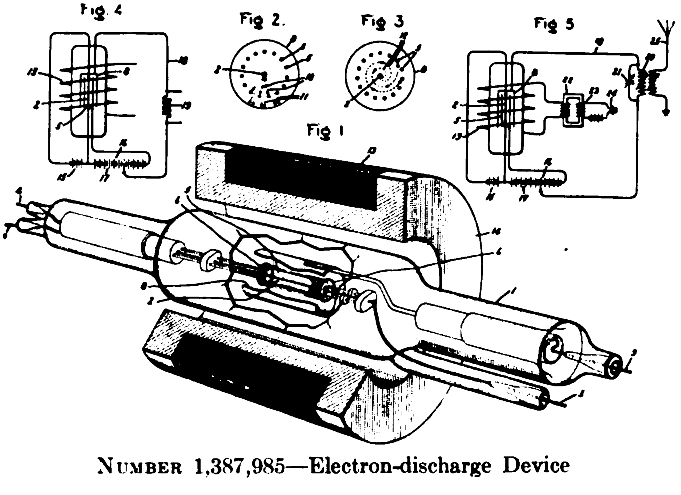
NEGATIVE RESISTANCE, or a device in which the current will decrease as the potential applied thereto increases, in contradistinction to the ordinary resistance devices in which an increase of potential is accompanied by an increase in current. The device is shown in Figure 1. If the cathode is connected to earth and heated to incandescence and a positive potential impressed upon the anode, there will be a flow of electrons from cathode to anode. If the third electrode is also at earth potential, no electrons will be received thereby because it is at the same potential as the cathode. If, however, a small positive potential is applied to the third electrode, a portion of the electrons which pass thru the grid anode will strike it and it will receive a current of negative electricity. The velocity with which these electrons will strike the third electrode will depend upon the potential difference between it and the cathode. If



Number 1,387,984—Negative Resistance

this potential is increased, the velocity will increase until the electrons striking the third electrode are able, by their impact, to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased, a point will finally be reached at which the number of secondary electrons leaving the third electrode is just equal to the number of primary electrons that strike it, that is, each electron that strikes it liberates on the average one secondary electron. No current will then be received by the third electrode. If the potential of the third electrode is further increased, the number of secondary electrons given off becomes greater than the number of primary electrons received and as a result the third electrode loses electrons, thereby supplying current to the anode instead of receiving current.

1,387,985—Albert W. Hull, Schenectady, New York, filed November 13, 1916, issued August 16, 1921. Assigned to General Electric Company.



NUMBER 1,387,985—Electron-discharge Device

ELECTRON-DISCHARGE DEVICE, which is controlled by a magnetic field set up about the tube. The stream of electrons from the cathode to the third electrode produces from the third electrode an emission of secondary electrons sufficiently to give the device a negative resistance characteristic. The variable magnetic field controls the stream of electrons, thereby varying the number of primary electrons which can reach the third electrode.

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THE AVALON-LOS ANGELES RADIO TOLL CIRCUIT*

By

Lewis M. Clement and Francis M. Ryan

(Research Laboratory of the American Telephone and Telegraph Company and the Western Electric Company, Incorporated)

and

De Loss K. Martin

(American Telephone and Telegraph Company)

Since last summer it has been possible for subscribers served by the Bell Telephone System to call any subscriber at Avalon, Santa Catalina Island, by telephone. This connection makes use of the Avalon-Los Angeles toll circuit with its radio link between Long Beach, on the mainland and Pebbly Beach, Santa Catalina Island, California.

The purpose of this paper is to describe the system employed and the apparatus which makes up the radio link, its installation and some of the features of operation and maintenance. Before discussing the apparatus itself, it may be well to say a word about the location of the circuit, the need for telephone service and the preliminary arrangements.

The Island terminal is located in the city of Avalon on Santa Catalina Island, approximately 30 miles (48 km.) off the coast of Southern California (See Figure 1). The population of the Island is concentrated at Avalon, altho there are a few people at Middle Ranch and others at the Isthmus. Avalon is a well-known summer and winter resort noted for its ideal climate, bathing, big game fishing, and other attractions. A view of the city of Avalon showing the main street is shown in Figure 2. The average yearly permanent population of Avalon is about 1,000, while the population during the summer months is probably between 10,000 and 15,000.

In the past, the only means of communication was the daily steamer to the Island from San Pedro. In 1902 this was supplemented by a radio telegraph service, one of the first commercial stations in the United States operated by the Pacific Wireless Telegraph Co.[1] This service was maintained with various degrees of satisfaction and duration successively by the United Wireless Telegraph Company, Marconi Wireless Telegraph Company of America, and at the present time† is operated by the United States Naval Radio Service.

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*Received by the Editor, May 4, 1921. Presented before The Institute of Radio Engineers, New York, May 4, 1921.

In the past the only telephone service around the city of

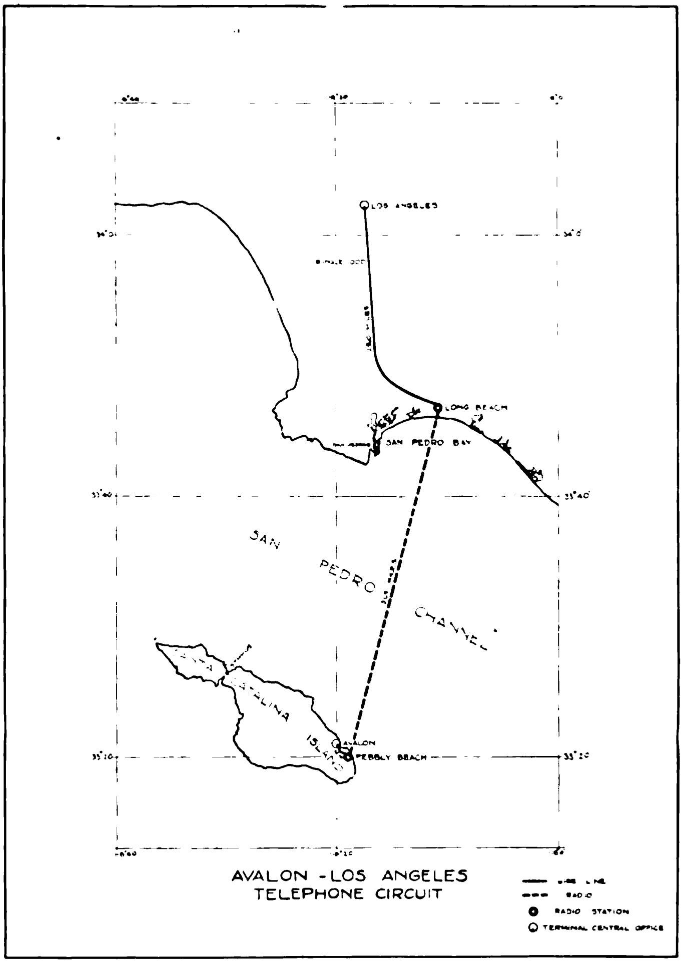

Figure 1—Avalon-Los Angeles Telephone Circuit

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[1] Marriott, "United States Radio Development," Proceedings of The Institute of Radio Engineers, June, 1917.

† Since the preparation of this paper this service has been discontinued, and all telegraph traffic to and from Avalon is handled by the simultaneous duplex telegraph channel mentioned at the close of this paper.

Avalon was given by a few private circuits including a line to the Isthmus. The need of the transient and permanent population of the Island for a more dependable means of communication between different points on the Island and between the Island and the vicinity of Los Angeles lead to a real demand for telephone service.

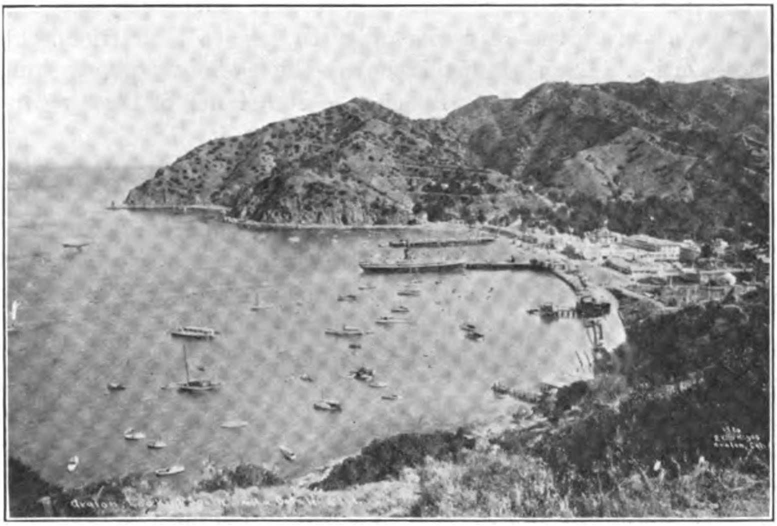


Figure 2—City of Avalon

Early in May, 1920, it was estimated that it would be practical to establish telephone service to the mainland by making use of a radio telephone connecting link between the wire circuits which would be established on the Island and the existing wire circuits on the mainland. It was believed that such a system could be completed and be in operation by July, 1920.

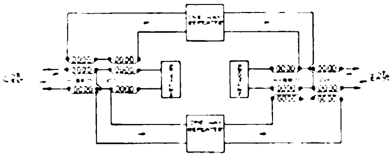
After these estimates had been carefully considered it was decided to start work immediately on the design and manufacture of the necessary radio and wire terminal equipment, and at the same time to start the installation of the necessary wire facilities at Avalon, the latter to consist of a telephone exchange, pole lines, and subscribers' terminal stations, which portion of the work was cared for by The Pacific Telephone and Telegraph Company.

The actual design and construction of the radio apparatus was started on May 10, 1920. Installation and preliminary tests of this equipment at the sites chosen for the stations were completed so that commercial service was inaugurated on July 16, 1920, 68 days after work was started in New York. On the previous day an official trial was given the complete system for the benefit of the officials of The Pacific Telephone and Telegraph Company, the leading citizens of Avalon and others. Connections were established between Avalon and Los Angeles, San Francisco, Chicago, and New York, so that the people who had gathered were given an opportunity to talk to their friends in these cities. Each circuit included the radio telephone link from the Island to Long Beach, the remainder of the circuits being part of the plant of the Bell system.

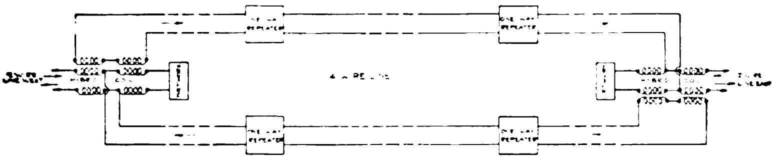
DESCRIPTION OF SYSTEM

Any radio telephone circuit which is to form a part of a commercial telephone system not only must be capable of duplex operation, but must allow of ready connections to ordinary two-wire telephone circuits. The duplex requirement was met, in the case of the radio portion of the Avalon-Los Angeles circuit, by the use of different carrier frequencies for transmitting in the two directions. The station at Pebbly Beach transmits a carrier of 750 kilocycles (wave length of 400 m.) and the one at Long Beach a carrier of 638 kilocycles (wave length of 470 m.).

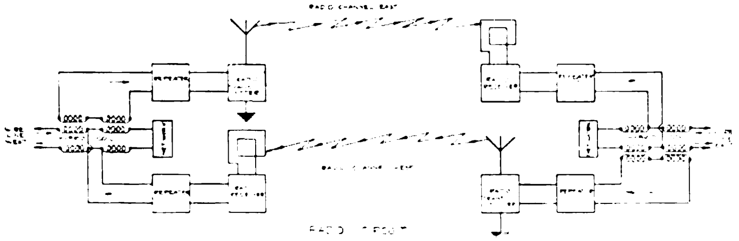
The problem of connecting such a radio link with two-wire telephone circuits at each end is similar to that of providing two-way operation when using one-way repeater elements such as mechanical repeaters or vacuum tubes. The experience acquired with such repeater circuits was directly applicable to this problem. The upper sketch in Figure 3 shows the circuit of the most usual type of two-way telephone repeater. This repeater circuit employs separate elements for amplifying the speech currents in the two directions. These elements are in a four-wire circuit and connection with the two-wire circuits is made thru special output transformers, often called hybrid coils. These transformers, together with their associated lines and networks, form alternating current bridges. The networks are circuits designed to have, as nearly as possible, impedance characteristics identical with the lines thay are to balance. If the balances are perfect, none of the output from either of the repeaters reaches the input circuit of the other repeater, the output current dividing equally between the line and network in each case and inducing no voltage in the input winding. However, if the balance is not perfect, as is always the case in practice, the current flowing into the line is not exactly equal to that flowing into the network and some voltage will be induced in the input coil. This results in a circulating current flowing in the four-wire portion of the circuit thru the two repeater elements. If the transmission loss around this circuit is less than the amplification or gain in the repeaters, "singing" results. The precision with which the networks may be made to balance the connecting lines largely determines the transmission loss around this circuit and in turn limits the amplification which may be obtained with such circuits without "singing." In the commercial operation of repeaters it is necessary to use gains very considerably below the "singing point" in order that speech distortion may be avoided.



TWO WAY 22 TYPE REPEATERS



FOUR WIRE CIRCUIT AND REPEATERS



RADIO CIRCUIT

FIGURE 3—Schematic Diagram of "22" and 4-wire Repeaters and Radio Circuit

The middle sketch in Figure 3 shows the four-wire circuit which is used to a considerable extent in the long-distance cable circuits of the Bell plant. It is to be noted that this circuit is similar to that of the "22 type" repeater shown above, the four-wire portion of the circuit having been expanded and the repeater elements placed at suitable intervals. The balance conditions necessary in this circuit are similar to those in the case of the "22 type" repeater.

The lower circuit in Figure 3 is of a radio telephone system which meets the requirements of duplex operation and terminal connection to two-wire telephone circuits. The similarity to the two repeater circuits described is apparent: the four-wire portion has been replaced by two one-way radio telephone channels. Amplification takes place not only in the repeater in this circuit, but also in the radio transmitter and receiver. In order that this circuit may be stable the total transmission loss in the two radio channels, and from one to the other thru the hybrid coils, must be greater than the total gain in the repeaters and radio equipment. If this condition is not fulfilled the system will "sing" around the two radio channels in a manner exactly similar to the "singing" in the four-wire portion of the repeater circuits. However, if the balance between the networks and their respective lines is accurate enough, it is quite possible to operate such a system with a considerable gain in transmission or amplification between the two connecting wire circuits. Similar types of circuits have already been so thoroly treated[2] that they will not be dealt with further except insofar as special problems related to the Avalon-Los Angeles circuit are discussed.

CIRCUITS

Figure 4 shows schematically the Avalon-Los Angeles circuit consisting of a little more than 1 mile (1.6 km.) of wire line from the Avalon central office to Pebbly Beach, a 31.5 mile (50.4 km.) radio link to Long Beach, and 25 miles (40 km.) additional wire circuit to Los Angeles. This combination wire and radio circuit is operated as a unit providing thru telephone and signaling from Avalon to Los Angeles. At Avalon the circuit may be connected with any subscriber's line and at Los Angeles to any local subscriber's line thru local exchanges or with other long distance lines reaching practically any subscriber in the Bell System.

The general circuit arrangement is indicated in Figure 5 which is a schematic of the Long Beach Station. The heavy lines in this figure show the speech circuit and the light lines the signaling system. For simplicity only the principal connections are shown.

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[2] Gherardi and Jewett, "Telephone Repeaters," "Transactions of the American Institute of Electrical Engineers," 1919, page 1322.

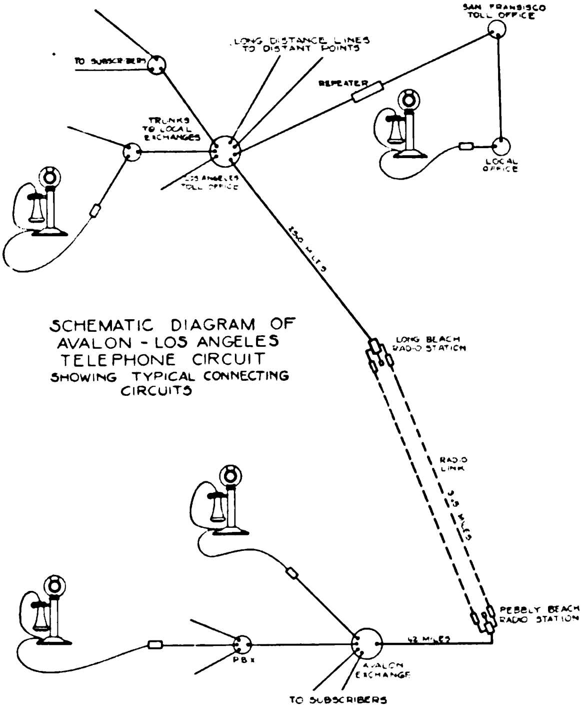
SAN FRANSISCO TOLL OFFICE
LONG DISTANCE LINES TO DISTANT POINTS
TO SUBSCRIBERS
REPEATER
TRUNKS TO LOCAL EXCHANGES
LOCAL OFFICE
LOS ANGELES TOLL OFFICE
SCHEMATIC DIAGRAM OF AVALON - LOS ANGELES TELEPHONE CIRCUIT SHOWING TYPICAL CONNECTING CIRCUITS
LONG BEACH RADIO STATION
RADIO LINK
30 MILES
PEBBLY BEACH RADIO STATION
PBX
AVALON EXCHANGE
TO SUBSCRIBERS

FIGURE 4—Schematic Diagram of Avalon-Los Angeles Telephone Circuit

Speech currents received from the Los Angeles line pass thru the cordless switchboard to the hybrid coil and to the network inducing similar currents in the input winding connected to the send repeater. This repeater amplifies these speech currents and delivers them to a low-pass filter which freely passes the principal speech frequencies of from 200 to 2,000 cycles, but greatly attenuates currents of frequencies higher than 2,200 cycles. Experiments have shown that only the band of frequencies from 200 to 2,000 cycles need be transmitted to deliver commercial quality and readily understandable speech and therefore the use of this filter does not impair to any appreciable extent the quality of transmission. The filter serves two purposes: it prevents interfering currents of frequencies above the necessary speech range from entering the radio transmitter, and it makes the balancing of the line with a suitable network somewhat easier in that the balance must be effective only for frequencies below 2,200 cycles. The output currents from the filter are delivered to the radio transmitter where they are further amplified and employed to modulate the radio frequency carrier current there generated.

The cordless switchboard provides convenient means for testing and monitoring on the circuit and for connecting quickly with another wire line in case of trouble in the wire portion of the circuit. In Figure 6 the hybrid coil, repeaters and signal units are shown as associated with the radio transmitter and receiver. All of this apparatus is mounted in the ends of a flat-top desk which supports the radio receiver and the cordless switchboard. At the rear of this desk is a battery control board providing means for measuring and controlling filament currents as well as protection for both the plate and filament circuits. Alarms are provided which notify the attendant in case any fuse blows. Figure 7 is a photograph of one end of this desk showing the send repeater and the sending unit of the signaling system and Figure 8 a photograph of the battery control board.

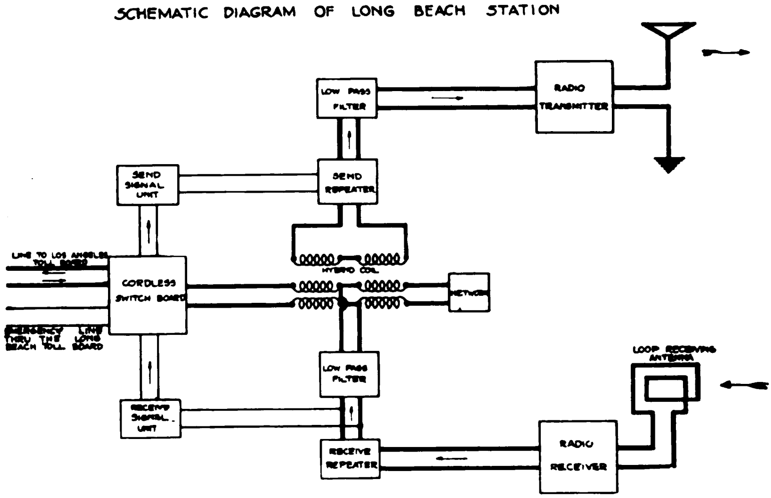

FIGURE 5—Schematic Diagram of the Long Beach Station

The send repeater (Figure 6) employs two tubes, the first, principally a voltage amplifier, and the second capable of delivering a relatively greater current output. Each of these tubes has the speech input voltage controlled by a potentiometer and by means of these the repeater gain can be adjusted to a suitable value, gains equivalent to more than 40 miles of standard

cable[3] being obtainable. Figure 6 also shows the electrical structure of the low-pass filter, the function of which has already been mentioned.

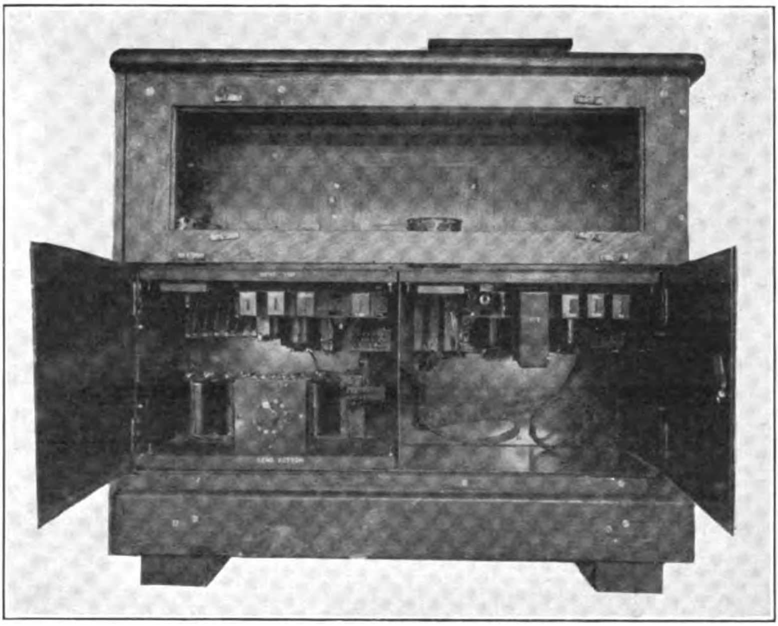

FIGURE 7—View of the End of the Repeater Desk

A loop antenna is used for receiving at each of the radio stations of this circuit. These loops are of the solenoidal type, six feet (1.83 m.) square and consist of only four or five turns each. How this loop is associated with the receiving equipment is shown in Figure 6. It was mentioned that the duplex feature of operation was attained by the use of different carrier frequencies for transmission in the two directions. In order to prevent, as far as possible, currents of the transmitting frequencies entering the receiver, an anti-resonant circuit adjusted to have a maximum impedance at the transmitting carrier frequency is included in the loop circuit and forms an effective filter. Figure 9 is a selectivity curve of the receiver showing the attenuation suf-

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[3] The "mile of standard cable" is a convenient measure of transmission volume which has found extensive use in telephone engineering.

The transmission equivalent of any circuit or apparatus is equal to the number of miles of standard cable which will cause an attenuation at 800 cycles the same as that experienced by the current in the circuit in question.

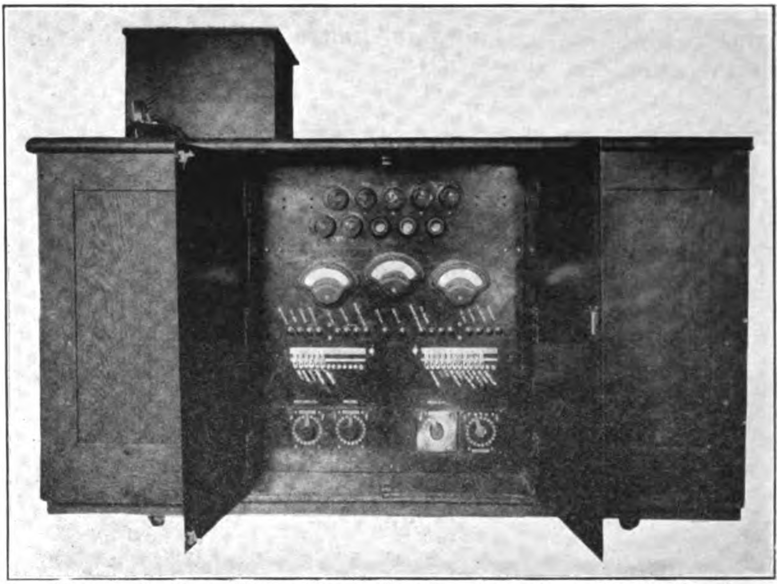

Figure 8—Rear View of Desk Showing the Battery Supply Panel

fered by currents outside of the desired transmission band, and Figure 10 is a photograph of the receiver.

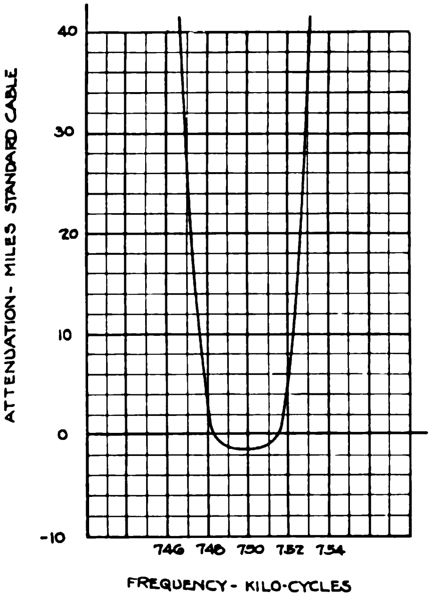

Figure 9—Selectivity Curve of the Radio Receiver

The speech frequency output currents from the radio receiver are amplified by the receive repeater which is similar to the send repeater already described and are delivered to a low-pass filter, the function of which is similar to that of the filter in the transmitting circuit. From the filter the speech currents flow to the hybrid coil, where they divide, half flowing into the network and half into the line. An interesting feature of the receiver is the provision of relays which close a buzzer alarm circuit when the filament of any vacuum tube fails.

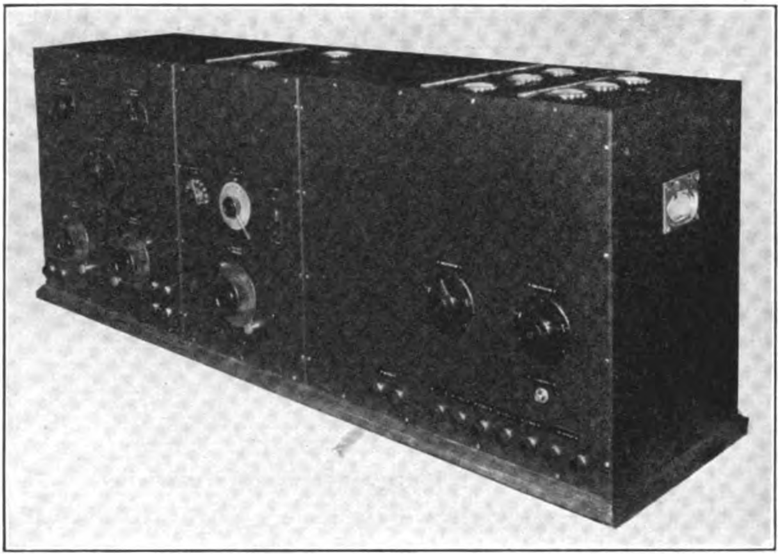

FIGURE 10—Radio Receiver

RADIO TRANSMITTER

The radio transmitter employs a circuit in which the oscillations are generated directly in the antenna circuit (Figure 11). The modulation of the radio carrier frequency is accomplished by the "constant current system"[4] in which both oscillator and modulator tubes, *G*, in this circuit are of 50 watts rating. These tubes are of the coated filament type, having relatively low filament power consumption and very constant operating characteristics. Figure 12 is a photograph of one of these power tubes.

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[4] Craft and Colpitts, "Radio Telephony," "Transactions of the American Institute of Electrical Engineers," 1919, page 305.

Heising, "Modulation in Radio Telephony," presented before THE INSTITUTE OF RADIO ENGINEERS, December 1, 1920.

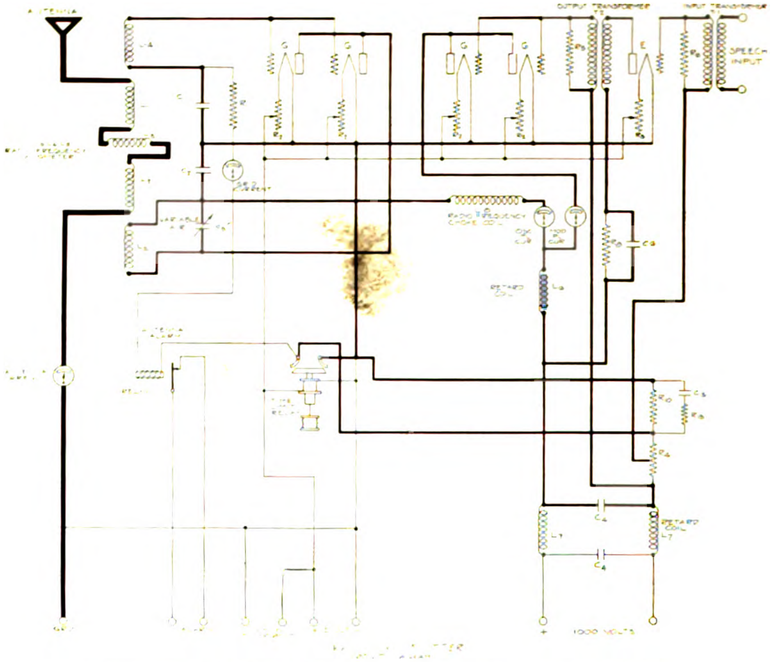

Figure 11—Circuit Diagram of the Radio Transmitter

Referring to Figure 11, the speech current is applied to the speech amplifier tube, *E*, thru the input transformer *T*-1. The output of this amplifier is impressed on the grid circuits of the two parallel modulator tubes thru the transformer *T*-2. The action of these modulator tubes is that of an amplifier and their output voltage is impressed on the plate circuits of the two oscillator tubes by means of the reactance L_6, which is common to the modulator and oscillator plate circuits. This modulation of the oscillator plate potential results in speech frequency variation of the amplitude of the antenna current. The frequency of the antenna current when not modulated is nearly that corresponding to the free period of the antenna circuit. It has been frequently shown[5] that a carrier current modulated by a single frequency is actually composed of three components, the carrier frequency and two side frequencies, one of a frequency equal to the sum of the carrier and modulation frequency, and the other of the carrier minus the modulation frequency. This conception of the nature of a modulated carrier current is essential to an understanding of the many problems of a radio telephone system. If instead of considering modulating with a single frequency, we consider modulation by the band of voice frequencies from 200 to 2,000 cycles, it is apparent that the result will not be simply two frequencies other than the carrier, but two bands of frequencies, one above and one below the carrier. For example, the Pebbly Beach station transmitting a carrier of 750 kilocycles, when modulated by speech, has the following frequencies present in the antenna circuit:

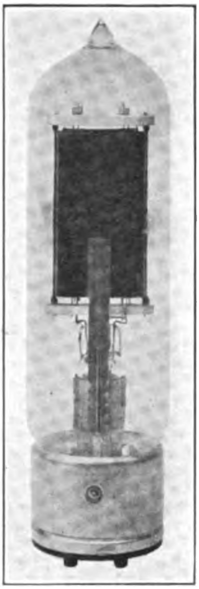

FIGURE 12—View of the 50-watt Tube

Carrier — 750.0 kilocycles
Upper Side Band — 750.2 to 752.0 kilocycles
Lower Side Band — 748.0 to 749.8 kilocycles

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[6] Craft and Colpitts, previous citation.
Ryan, Tolmie, and Bach, "Multiplex Radio Telegraphy and Telephony," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, December, 1920, page 451.

The transmitting antenna satisfactorily passes all of these frequencies as none of them differ as much as 3 per cent. from the resonant frequency and the impedance of this circuit is nearly equal to its resistance over this range.

Figures 13 and 14 are photographs of the radio transmitter and Figures 15 and 16 show the motor generator set and controlling switchboard supplying the plate and filament power for the transmitter. This motor generator set consists of 1,000 and 12 volt direct current generators driven by an induction motor. The filter consisting of the series retard coils L_7 and shunt condensers C_4 (Figure 11), serves the double purpose of protecting the 1,000 volt generator from the radio frequency potentials and smoothing out any commutator ripple or other machine noises which would tend to modulate the radio carrier and result in objectionable noises in the subscriber's instrument.

Two other important details of the radio transmitter circuit, as shown in Figure 11, are the method of obtaining and controlling the required negative grid potentials and the alarm provided to indicate failure of the oscillators. The negative grid potential for the speech amplifier, E, is obtained from the drop in potential in the upper part of the resistance R_4 and that for the modulator tubes from the entire drop in this resistance which carries the space current of all the tubes in the transmitter. A time limit relay is provided which is controlled by the filament circuit and which itself controls an auxiliary negatuve grid potential which results from the drop of potential in R_{10}. This negative potential is relatively large and results in the stopping of oscillations and the reduction of all space currents to a low value. This arrangement insures that the filaments will have reached normal temperature before the auxiliary grid potential is removed and therefore that no excessive space currents can flow during the period when the filaments are heating. If for any reason oscillations cease in the antenna circuit, the oscillator grid current also stops flowing and the relay shown in the oscillator grid circuit releases, actuating an alarm at the cordless switchboard.

Signaling System

Another interesting feature of the installation and one which is important in completing the commercial usefulness of the telephone circuit is that of the signaling system. By means of it the signals are not only passed over the radio telephone system itself, but are automatically relayed at the points of junction with the wire circuits so that the operators at the ends of the

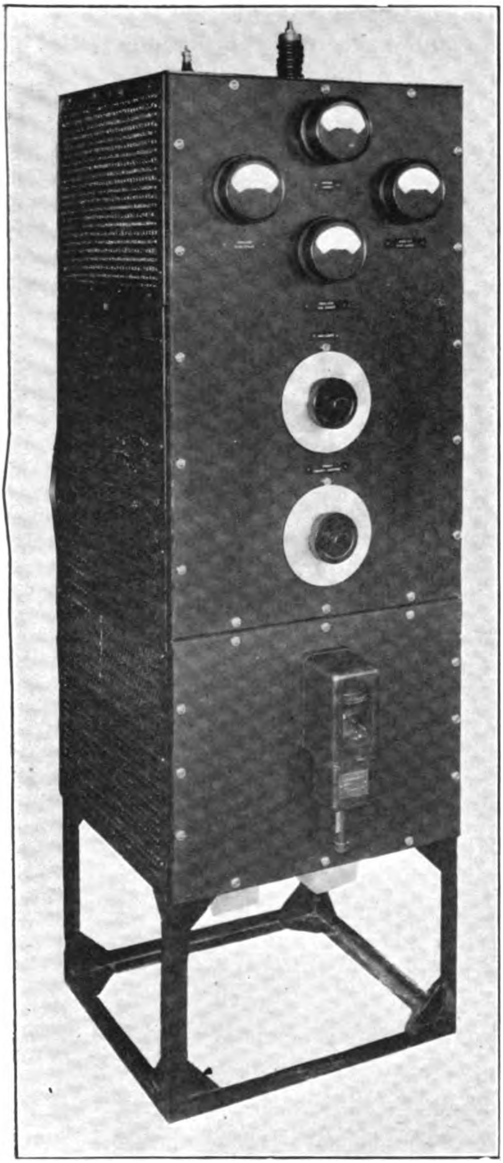

Figure 13—Radio Transmitter

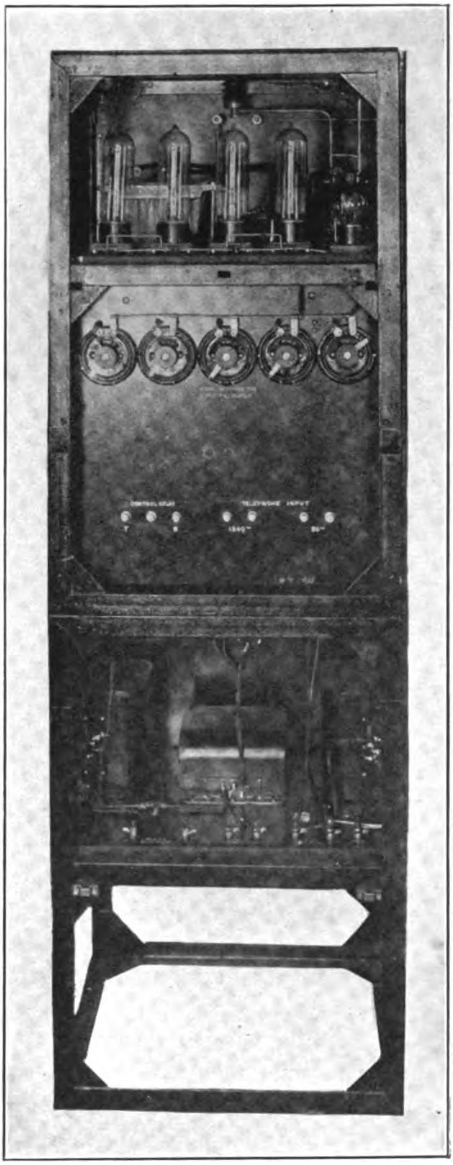

Figure 14—Radio Transmitter (Rear View)

thru radio-wire toll line may ring down a drop at the distant end of the circuit and operate a visual or audible signal. By means of this system, then, the thru circuit may be operated from the remote land line switchboards in a manner according with standard wire practice.

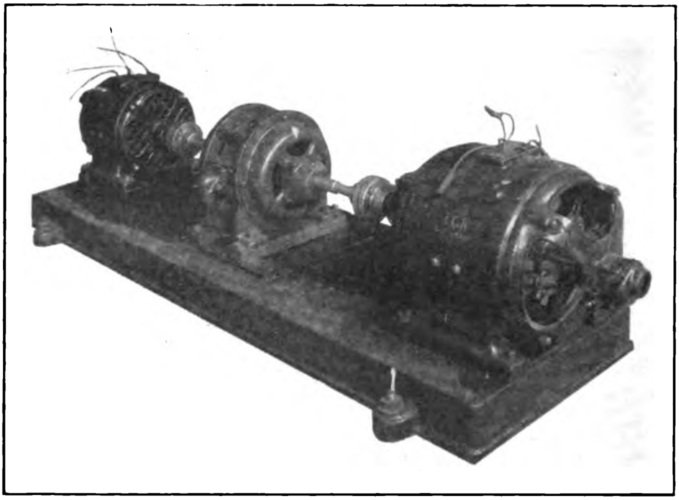

FIGURE 15—Motor Generator

Altho the requirements of the radio portion of the signaling system are somewhat rigid, the system in use has met them very satisfactorily. It has proven to be reliable, reasonably rapid, and free from false operation by interference from speech currents, circuit noises, static, or interference from other radio stations. The system represents an adaptation of a signaling arrangement originally developed for use on long distance wire circuits.

The manner in which the signal system is associated with the telephone and radio circuits is shown in Figure 6. The usual 16-cycle ringing current from the wire line actuates a relay which in turn controls three other relays. These latter relays disconnect the receive signal unit to prevent false signals, connect the output of the send signal unit with the second tube of the send repeater and energize the send signal unit. Upon reception of the signal impulses the relay in the output circuit of the receive signal unit releases and energizes another relay which disconnects the wire line from the hybrid coil and connects it with a source of 16-cycle signaling current. This same relay connects an auxiliary network to the line terminals of the hybrid coil maintaining a balanced condition and preventing "singing" during signaling. With this arrangement it is only necessary for the operator at Avalon to throw the usual ringing key and a light appears on one of the positions of the Los Angeles toll board and in a similar manner Los Angeles can signal Avalon.

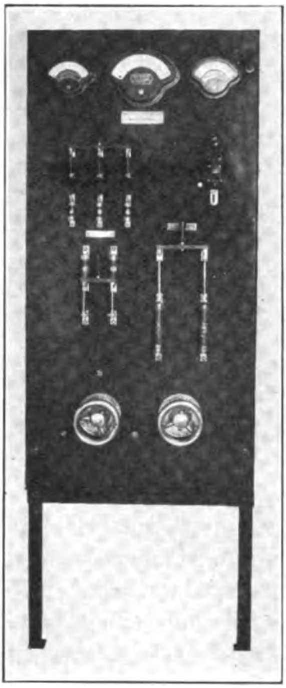

FIGURE 16—Power Panel

SELECTION OF STATION SITES

The sites for the radio stations were selected and the antenna and ground systems were designed and installed while the equipment was being built in New York. The mainland end of the link is located at Long Beach, California, first because Long Beach is so located with respect to the Englewood Radio Station and San Pedro Harbor that the directional effect of the loop antenna can be used to discriminate against this station and ship stations in San Pedro Harbor, and second because adequate power and telephone facilities were available at the Long Beach Toll Exchange. Figure 1 shows the location of the radio stations and the wire circuits connecting them to Los Angeles and Avalon. Figure 17 is a photograph of the Long Beach Toll Exchange and Figure 18 is a photograph of the Avalon Exchange.

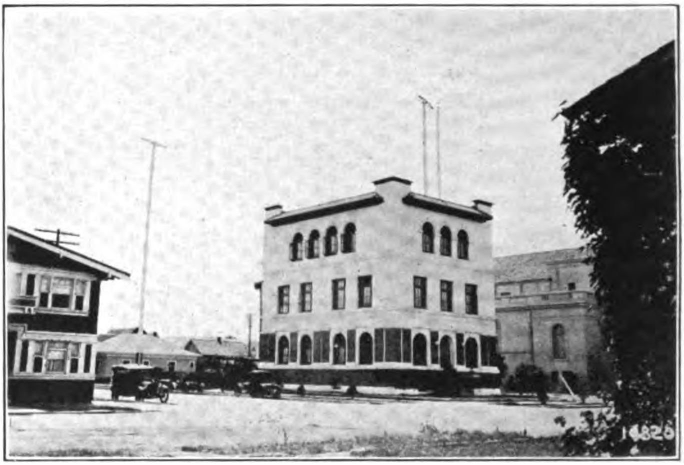

FIGURE 17—Long Beach Exchange

At Avalon there was no existing telephone plant and only one radio transmitting station, which was located practically at the center of the town on the water front. No site could be found which would at the same time satisfy wire center requirements and be at a reasonable distance from this spark transmitting station. Outside of the city proper, the only level stretch of ground suitable for a radio transmitter and antenna system was found at Pebbly Beach (Figure 19), which is about a mile and a quarter (2 km.) from Avalon.

ANTENNA AND GROUND SYSTEMS

Due to the short time available for construction purposes and further because it was desirable to use, as much as possible, types of construction already standard in telephone practice, the longest telephone poles that it was possible to secure locally are used to support the antenna. These poles are 90 feet (27.4 m.) long and are set on a special concrete and I-beam footing so that advantage is taken of the full height of the masts. Figure 20 shows the special footing supporting the pole which consists of four 8-inch (20.3 cm.) I-beams partly embedded in reinforced concrete. The I-beams are diametrically opposite each other with respect to the pole butt, and enough space is left so that the butt of the pole will fit snugly between them. The beams are then drawn tightly to the pole by bolts passing thru both. This footing is designed to have a bending moment sufficient to support the pole alone in a 90-mile (162 km.) an hour wind The poles are also guyed in four directions with 7 strands of number 12 B. W. G. galvanized steel messenger cable.* These guys are attached to the pole at a point 15 feet (4.6 m.) from the top to minimize as much as possible the effect of their presence in the field of the antenna. Each guy is broken into three sections by porcelain strain insulators.

FIGURE 18—Avalon Exchange

The wires of the T type antenna are supported by double cross arms which are bolted to the pole and have in addition a channel iron truss to stiffen the structure. Each antenna wire

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*Diameter of number 12 B. W. G. wire = 0.109 inch = 0.277 cm.

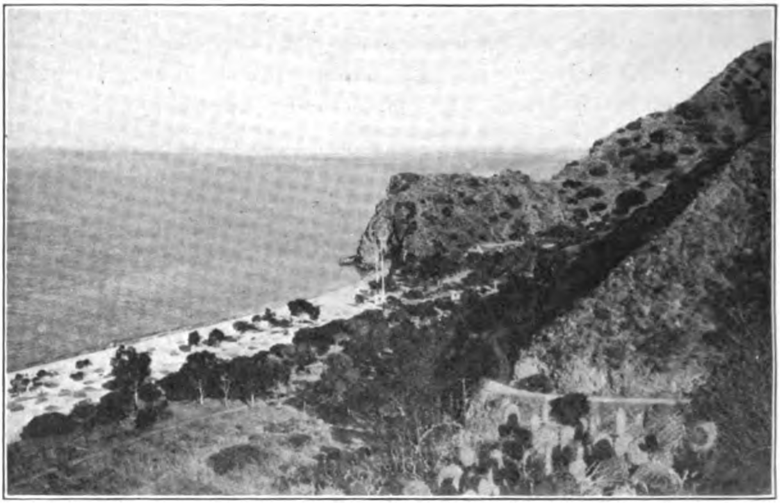

FIGURE 19—View of the Pebbly Beach Radio Station

is fastened to a long eye-bolt passing thru both cross-arms and secured with lock nuts. With this type of construction the tension in each individual wire can be regulated without affecting the tension of the other wires. Each wire is insulated from the

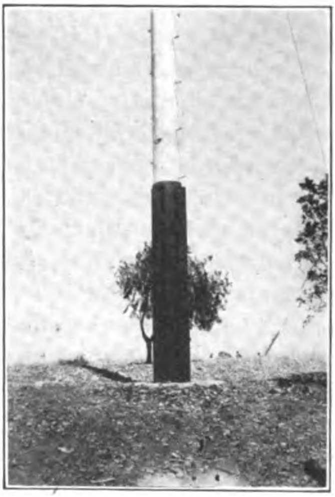

FIGURE 20—View of the Special Footing for the Masts

cross-arms by a series of four porcelain strain insulators. Figure 21 shows the details of the insulation and cross-arm construction while Figure 17 shows the completed antenna at Long Beach and Figure 22 the completed antenna at Pebbly Beach. The advantages of this rigid type of antenna construction are its strength and constant electrical capacity.

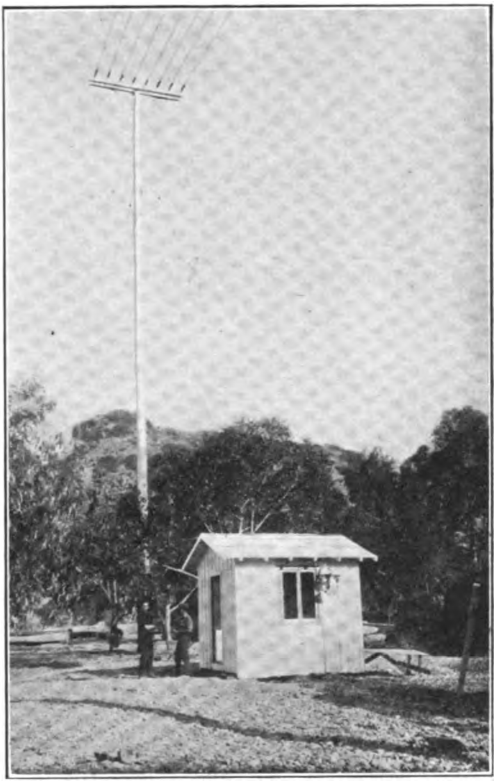

FIGURE 21—View of the Transmitter House, Showing the Mast and Antenna Construction

At each station a large area of buried ground conductor is used and in addition every piece of metal in the vicinity of the station is brought to ground potential. At Pebbly Beach, owing to a 16-foot (4.9 m.) layer of small rocks (see Figure 21) an extensive ground system buried a few inches in the rock is installed, which materially reduces the resistance of the antenna circuit.

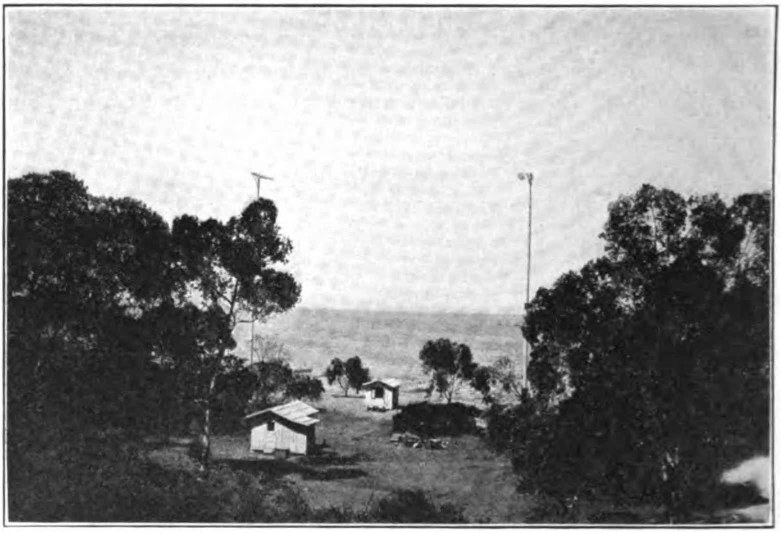

FIGURE 22—View of the Antenna System at Pebbly Beach

INSTALLATION OF SYSTEM

At the time the apparatus arrived from New York, the Long Beach antenna system was nearly completed and the power and telephone facilities were available. For this reason the apparatus was first installed and tested at Long Beach. The Avalon installation work was started while the houses were but partially completed and the installation of apparatus was practically complete when the antenna, the power, and telephone facilities were available.

The transmitter, power panel, and motor generator at Long Beach are located in the northeast corner of the apparatus room (second floor) of the Toll Exchange. (Figure 23.) The storage batteries for the radio receiver, the charging switchboard, and the charging motor generator are located along the south wall while the radio receiver, repeater, and terminal equipment are located in a small room on the 'southwest corner of the building. The disposition of the telephone as well as of the radio equipment is approximately shown on the floor plan, Figure 24. Some idea of the proximity of the transmitter, the antenna, and telephone equipment to the receiver can be gained from this figure. The power is supplied from the 220 volt, 3 phase, 50 cycle mains of the Southern California Edison Company, and no auxiliary power supply is available.

At Pebbly Beach the transmitting house is located under the center of the antenna system while the receiving house is one hundred feet (30.5 m.) away on a line perpendicular to the flat top of the antenna. Figure 22 shows the location of the buildings with respect to the antenna system and gives a general idea of the surrounding country.

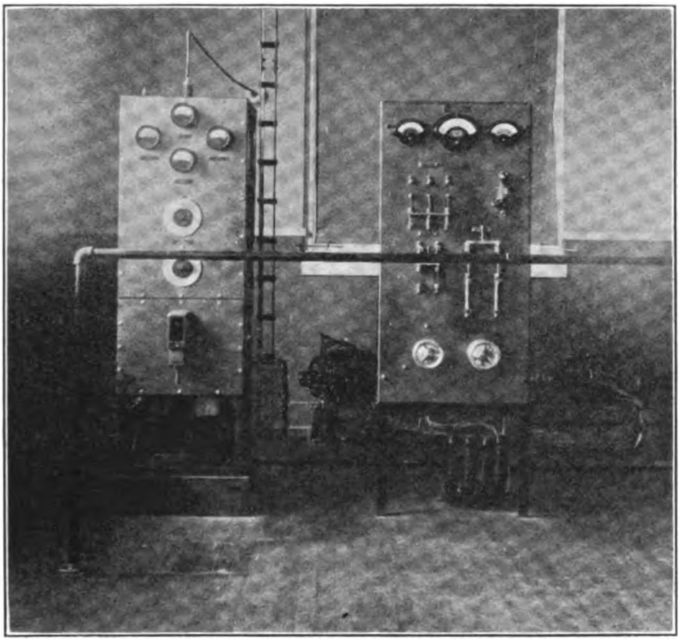

FIGURE 23—View of the Transmitter, Power Panel, and Motor Generator Installed at Long Beach

The radio transmitter power panel and motor generator, as well as the storage batteries for the radio receiver and repeaters, charging panel, and charging motor generator, are located in the transmitting house. The radio receiver, loop antenna, repeaters, signaling and terminal equipment are located in the receiver house. A photograph of the apparatus in the receiving house is shown in Figure 25.

All wiring between the two houses is in underground conduits which have been carefully grounded. The power supply is obtained from the municipal plant at Avalon and the single phase 2,200 volt leads together with three telephone lines are carried

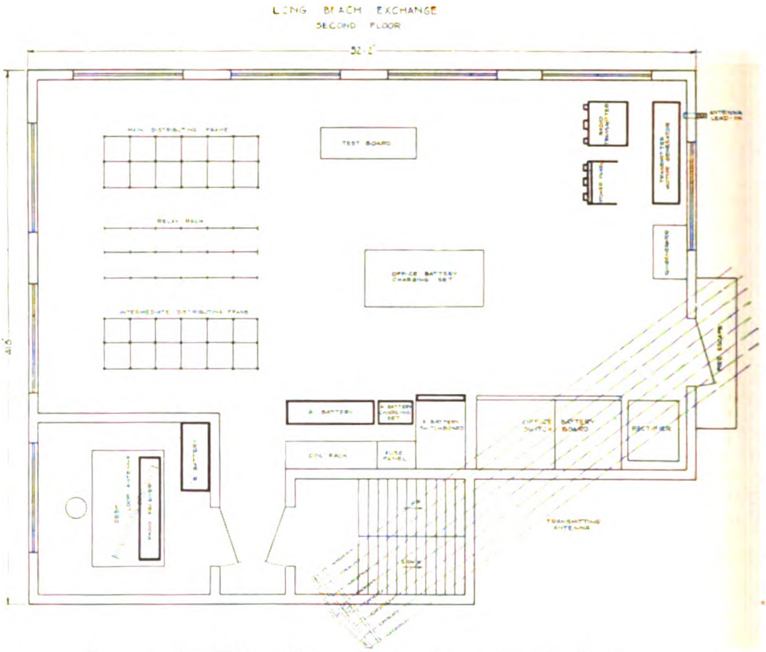

FIGURE 24—Floor Plan of the Long Beach Exchange

on a pole line to a point five hundred feet (153 m.) away from the radio station. The last pole of the line can be seen in Figure 19 to the right of the lower center portion of the photograph. A

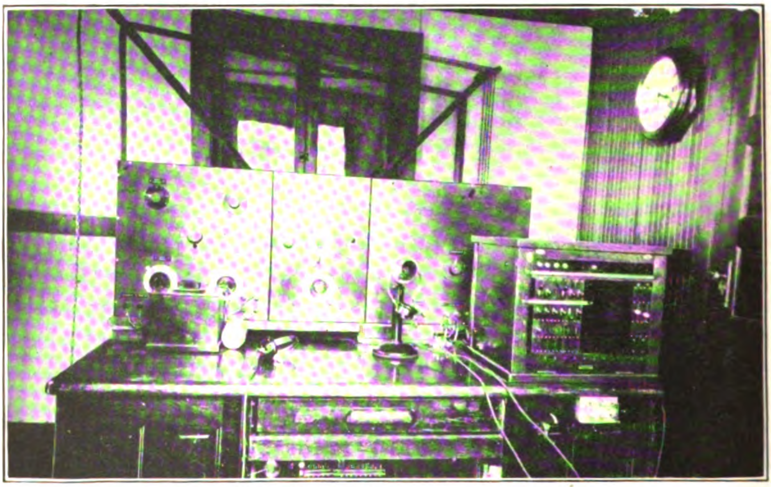

FIGURE 25—View of Receiving Equipment at Pebbly Beach

LINE
VARIA
FREQU
OSCIL

conduit to the transmitting house carries the 110-220 volt power leads and a ten pair telephone cable enters the receiving house thru a separate conduit.

SPECIAL PROBLEMS

The Pebbly Beach-Avalon and Long Beach-Los Angeles lines are so short that the terminations play an important part in their impedance characteristics. For example, the impedance of the line measured at the radio station with the far end open-circuited is materially different than when the far end is closed thru the impedance of a cord circuit and an average subscriber's loop. The lines terminate in jacks at the Avalon and Los Angeles toll boards. The cords used with these lines are specially equipped and never allow the lines to be opened under any switching condition. Figure 26 is a schematic of the circuit between the Pebbly Beach radio station and the Avalon exchange and shows a cord circuit, the dispatch operator's set, and the special circuits to maintain the balance of the line and network.

The network at the Pebbly Beach station is of such an impedance that it balances the line, a cord circuit, and an average subscriber's loop. The special circuit is so arranged that a network which simulates a cord circuit and an average subscriber's loop is always bridged on the line except when the connecting cord is plugged into a subscriber's jack and his receiver is off the hook. The network is controlled by the supervisory relay in the cord circuit and extra contacts on the line jack. A dispatch operator's set is permanently connected to the line and is provided with a high impedance monitoring connection which has little effect on balance or transmission of the circuit. This arrangement maintains the balance with sufficient accuracy to allow the circuit between the wire terminals at Pebbly Beach and the wire line at Long Beach to work at a net gain of more than 5 miles of standard cable.

Excessive cross talk between the transmitter and the receiver is prevented by carefully shielding all of the filament and plate battery leads and providing large by-pass condensers. This prevents such radio frequency currents as may be induced in the filament leads from entering the receiver and producing objectionable cross talk between the sending and receiving channels, which may cause local singing.

Noises due to telephone apparatus in the exchange, such as ringing machines, telephone relays, and so on, are eliminated by shunting each troublesome contact with a condenser and series resistance of the proper electrical constants.

Commutator ripple from the charging generator and a noise due to the intermittent grounding of the radio induction on the charging leads thru the commutator are entirely prevented by connecting a retard coil in series with the charging lead to the battery and draining off the radio frequency induced currents by connecting two condensers across the commutator and grounding the mid-point.

QUALITY OF SERVICE

Since this circuit is the only telephone channel between the Island and the Mainland, it was very heavily over-loaded from the day of opening until the cessation of the summer tourist traffic in the latter part of September. Due to the methods employed, the high grade circuit, and so on, a great deal more traffic is handled over this circuit than is generally handled by a single toll line.

A record of all of the interruptions to service is kept at both of the stations together with the cause of the delay, its duration, and other information. It is interesting to note that altho the circuit was open to commercial service during the worst of the static season, subscribers had but little or no difficulty in using the circuit. Transmitting frequencies of 750 and 638 kilocycles (400 and 470 meters) were chosen for the stations after an extensive survey of the ether, so that the telephone would cause least interference to and be interfered with the least by radio stations in the vicinity. Some trouble was experienced from the Avalon spark station located about one mile from the receiving station at Pebbly Beach. This station employed a transmitting frequency of 1,000 kilocycles (300 meters) while the Pebbly Beach station had its receiving apparatus tuned to receive 638 kilocycles (470 meters). Upon investigation it proved that the logarithmic decrement of the Avalon station greatly exceeded 0.3. When the decrement is kept below 0.2 little or no trouble is experienced from this station.

The circuit, due to the choice of sites, directional characteristics of the loop antennas, and selectivity of the radio receivers, is quite free from interference and it is only occasionally that an interfering spark signal is heard. The harmonics from the Poulsen arcs installed at the Naval Radio Stations at San Diego and Englewood, California, have given rise to some trouble. If the arc harmonic beats with the radio carrier and side frequencies of the radio telephone station at either an audible or nearly audible rate, the quality of the speech over the circuit may be affected materially. This is in effect the same result which obtains when speech signals are received on an ordinary heterodyne receiver when the local oscillator is not adjusted to the same frequency as that of the transmitter. Altho this trouble can be eliminated as soon as it is discovered by shifting the carrier frequency of the radio telephone transmitter a few thousand cycles, it is obvious that in the future, when many stations may be expected to be operating, this difficulty must be eliminated in a more rational manner.

Maintenance

The circuit is in operation sixteen hours per day, which covers the period 6:30 A.M. to 10:30 P.M. The largest items in the maintenance charges of a radio telephone and telegraph system are personnel, tube renewals, and power. The radio attendants play no part in the actual handling of traffic, but look after the maintenance of the equipment in the same way that a wire repeater attendant maintains the repeater equipment. It may be mentioned in this place that it is not necessary frequently to change the adjustments of the tuned circuits of either the transmitter or receiver.

Separate Auxiliary Receiver

A receiver capable of receiving signals on 500 kilocycles (600 meters wave length) is installed at Long Beach. The flagpole on the exchange, which is approximately thirty feet (9.2 m.) from the transmitting antenna, supports a single wire vertical antenna. An anti-resonant circuit tuned to the local transmitter frequency is connected in series with the antenna lead. This receiver using a detector and two-stage amplifier makes it possible to receive signals of all frequencies except a narrow band near the local transmitting frequency of 638 kilocycles.

Transmission Measurements

The transmission equivalent of the circuit from the wire line at Pebbly Beach to the wire line at Long Beach has been studied by employing methods and apparatus in general use in the Bell plant. The apparatus employed was the same as that used when it is desired to measure the equivalent of a wire telephone toll circuit. Figure 27 shows schematically the circuit and apparatus used in making these measurements. At each radio station the wire line was disconnected and the line network replaced by a 600 ohm resistance which insured a balance with the sending and receiving measuring units which were substituted for the lines. At each station a calibrated variable frequency oscillator was provided which delivered a current measured by a thermocouple milliammeter to a 600 ohm network. At Pebbly Beach this network was connected to the line terminals of the hybrid coil. At Long Beach a unit consisting of an amplifier and rectifier with its meter provided means of indicating like strength of measuring current. In addition to this equipment two artificial lines were provided, one having a fixed attenuation and the other being variable. The measurement of the transmission equivalent was made in two operations. In the first of these the oscillator at Long Beach was connected to the indicating unit thru the fixed artificial line and the frequency of the oscillator adjusted to the desired value. The oscillator output current (as indicated by the thermocouple milliammeter) is then adjusted to a suitable value and the potentiometer at the input of the indicating unit adjusted to give a convenient value of rectified current. The second operation consisted of connecting the indicating unit thru the variable artificial line to the line terminals of the hybrid coil and at Pebbly Beach adjusting the oscillator to deliver exactly the same current and the same frequency as the Long Beach oscillator. The variable artificial line was then adjusted until the rectified current in the indicating unit was the same as that obtained during the first operation. It is then apparent that the transmission equivalent of the circuit from the oscillator used to the indicating unit was the same for each operation as similar oscillator outputs delivered equal inputs to the indicating unit. In the first case this circuit was simply the fixed artificial line and in the second it was the radio link plus the variable artificial line. The transmission equivalent of the radio link is therefore the equivalent of the fixed artificial line minus that of the variable artificial line. The apparatus was so arranged that the desired transmission equivalent could be read directly. It is to be noted that in case the equivalent of the variable line exceeds that of the fixed line the transmission equivalent of the circuit is a negative value, indicating a gain in transmission. This was the case with the radio link.

Transmission measurements were made at two different times between the two stations to determine the variation in transmission from hour to hour thruout the twenty-four hours. Figure 28 is a curve showing the results of one of these tests.

The maximum variation from the mean is seen to be only two miles of cable which ordinarily is not noticeable to the average person. Most of this variation, it is believed, was due to variation of voltage at the stations beyond the control of the observers. The transmission between the two radio stations is therefore, practically the same thruout the twenty-four hours of the day, as was to be expected for such a short radio link.

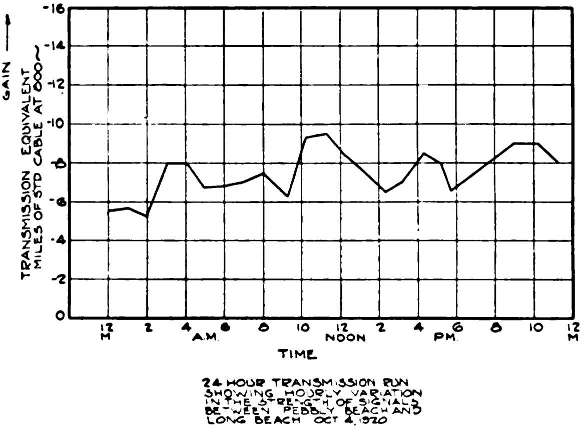

FIGURE 28—24-hour Transmission Run, Showing Hourly Variation in Transmission

FREQUENCY TRANSMISSION CHARACTERISTIC

In order to study quantitatively the ability of the circuit to transmit good quality speech, a frequency transmission charactertic of the circuit was taken. This was accomplished by measuring the equivalent of the circuit in miles of standard cable for several different frequencies between 250 and 2,400 cycles per second. Figure 29 is such a characteristic of the circuit between Pebbly Beach and Long Beach with reception done at Long Beach and shows that the frequency transmission characteristic is reasonably flat.

The effect of the filters is clearly shown by the sharp bend of the characteristic at about 2,000 cycles. The lower frequencies in the speech range are responsible for the naturalness of a speaker's voice while the higher frequencies contribute toward the understandability.

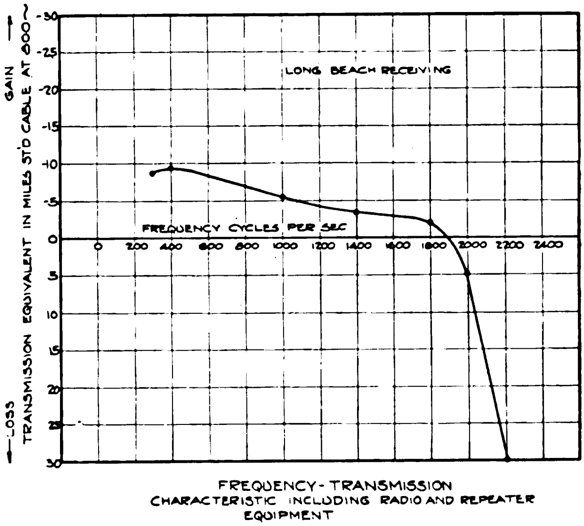

FIGURE 29—Frequency Transmission Characteristic

GENERAL CONSIDERATIONS

The large amount of commercial traffic which the Avalon-Los Angeles Toll Circuit has handled every day since July 16, 1920, is ample proof of the practicability of operating toll circuits containing radio telephone links.

The volume of speech and the quality of transmission are such as to allow of satisfactory connections to the longer telephone circuits of the Bell System. This is quite aptly illustrated by a connection which was established between the steamship *Gloucester* on the Atlantic Ocean and Avalon, Santa Catalina Island. Starting from the ship the following circuits were used:

(a) Steamship *Gloucester* to Deal Beach, New Jersey, via radio.

(b) Deal Beach to New York, via telephone line.

(c) New York to San Francisco, via trans-continental telephone line.

(d) San Francisco to Los Angeles, via telephone line.

(e) Los Angeles to Avalon, thru the Long Beach and Pebbly Beach radio equipments.

Figure 30 is a map showing the route taken by the various sections of the line showing the repeater and radio stations which enabled the conversation to be carried on. The success of such a conversation naturally depends, not only on the transmission over the radio, but over the far greater wire portion of the circuit.

In addition to the telephone facilities described an experimental duplex telegraph channel was installed operating simultaneously with the telephone. This telegraph channel makes use of the ordinary Morse instruments and may form a part of any thru line telegraph circuit. Experimentally, this circuit has been operated in conjunction with existing telegraph circuits to give thru duplex telegraph connection between Avalon and San Francisco, California.

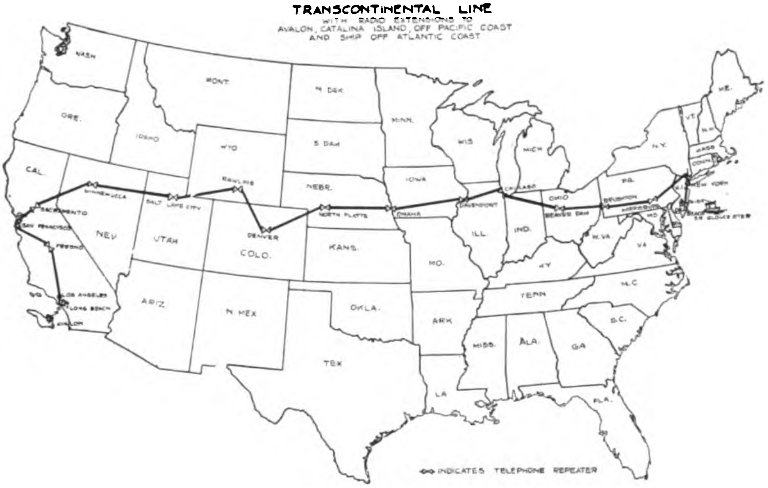

Figure 30—Trans-continental Line with Radio Extensions to a Ship and Avalon

SUMMARY: The communication facilities of Santa Catalina Island are described with special reference to the radio telephone service to the Californian mainland and the mode of connection to the wire telephone networks at the ends of the radio telephone channel. The radio telephone link is full duplex, and is connected thru special two-way repeaters to the telephone system at each end. A simultaneous duplex radio telegraph channel is available. A number of special points are discussed, such as the narrowing, by means of filters, of the side frequency bands due to modulation, the circuits of the transmitter and receiver, automatic alarm systems indicating when any portion of the radio equipment ceases to function, thru signaling system, location, and antenna and ground arrangements. The service rendered is analyzed and the results of transmission measurements are given.

A VISUAL AND PHOTOGRAPHIC DEVICE FOR RECORDING RADIO SIGNALS*

By

Charles A. Hoxie

(General Electric Company, Schenectady, New York)

Altho the instrument here described is, as it stands today in its latest form, particularly adapted to the recording of radio signals at high speed, the recording or high-speed features were not considered when the work was begun. The first model was designed and built to produce a device that would enable the signals to be seen instead of being read by ear in the ordinary way by means of the telephone. The main reason for this development was the fact that in the early attempts to equip airplanes for radio reception, difficulty was experienced in hearing the signals.

It was thought that if the eye could be substituted for the ear, much better results could be obtained, and in order to do this successfully, it was decided that the instrument should possess the following characteristics:

1. It should be sufficiently sensitive to record a signal of a strength equal to that required for ordinary telephone reception.
2. The action should be quick enough to record clearly the dots and dashes when received at a maximum speed of approximately 12 or 15 words per minute.
3. It must operate equally well in any position.
4. It should be of rugged construction.
5. It should not easily be put out of adjustment.
6. It should be selective, so as to pick out and record only the signals desired.
7. It should not respond to impulses such as are caused by atmospheric disturbances (static), tube noises, and so on.

In order to meet all of these requirements it was necessary

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to construct a special type of instrument. The galvanometer, as first constructed, consisted of a thin strip of iron stretched between the poles of two permanent magnets. Coils of wire were placed around the poles of the magnets, the terminals of which led to the receiving set. A small shaft mounted in jewels and free to turn on its axix, carrying a small mirror, was connected by means of a wire to the strip of iron, or vibrator.

When a current due to the receiving signal traversed the coils, the vibrating strip of iron moved to and fro between the poles of the magnet, thereby causing the shaft to rotate thru a very small angle which in turn vibrated the mirror. A beam of light from a lamp having a single straight filament was allowed to fall on this mirror, and an image of the filament, by means of a spherical lens just in front of the mirror, was projected on to a surface of ground glass. When no signals were being recorded, a single light line was visible on the ground glass. When a dot or dash caused the mirror to vibrate, the line would apparently become broad, due to the very rapid vibration of the mirror. The line becoming broad for a short time represented a dot and for a relatively long time, a dash. In this manner signals could be read.

This first galvanometer required a signal that would be considered fairly strong for telephone reception in order to produce a readable deflection. The action was quick enough for speeds up to approximately 30 words per minute. It could be held in any position without interfering with its operation, the small mass of the shaft and mirror being held firmly in position by the connecting wire, to the vibrating reed, the mirror being affected only by the very minute and rapid vibration of the iron strip. This also tended to make the instrument very rugged. It could even be shipped by express without danger of being put out of adjustment. It had a natural period of approximately 1,000 cycles, and was sensitive only when the frequency of the incoming signal accurately corresponded to the natural period of the galvanometer. Two or three per cent above or below this frequency reduced the deflection to zero unless the signal was abnormally strong.

Means were provided for varying this period from about 800 to 1,200 cycles, by putting more or less tension on the vibrating strip. The most important of its characteristics, however, was the fact that it did not respond readily to atmospheric disturbances or to the ordinary tube noises so frequently present in the average type of amplifiers. Figure 1 is a photograph of the first model constructed.

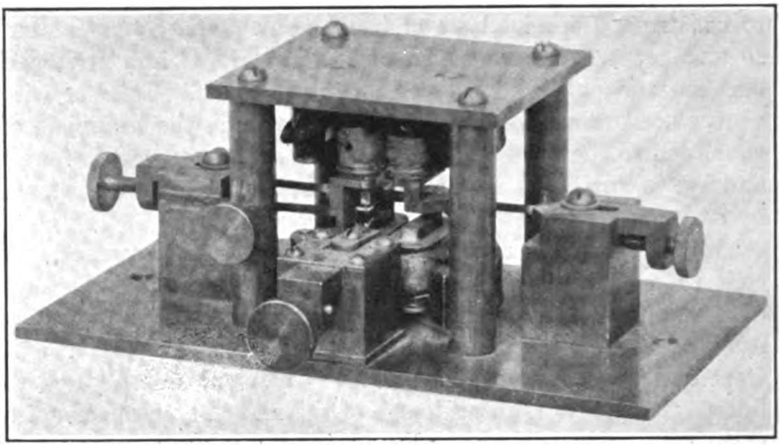

Figure 1—First Model of Galvanometer for Visual Reception

A summary of its characteristics show, then, that the requirements regarded as necessary for successful operation, were met, except that in the first and seventh, there was chance for improvement. Taking them in the order given:

1. It was fairly sensitive.
2. The action was sufficiently quick to meet the requirements.
3. It was not affected by position.
4. It was rugged.
5. It was not easily put out of adjustment.
6. It was selective.
7. It did not respond readily to static impulses, and so on.

A second instrument was then built for visual reception, a photograph of which is shown below (See Figure 2). The size of this instrument was approximately 8 inches (20.3 cm.) wide, 6 inches (15.2 cm.) deep, 22 inches (55.9 cm.) long. It could either be held in the arms while reading the signals, or supported otherwise at will. A hood projected over the ground glass, on which the beam of light was projected, in order more easily to see the signals. An enlarged view of this galvanometer is shown in Figure 3. Signals could be easily read by the visual method up to about 15 words per minute, but it was very trying to the eyes to read steadily for any great length of time, and for this reason it was believed to be impractical.

It was then decided to develop an instrument that would photographically record the signals. Within the next year, models of three different types were constructed; and after giving a brief description of these, I shall describe at length a later type of which several have been made and are now in use in various trans-Atlantic receiving stations.

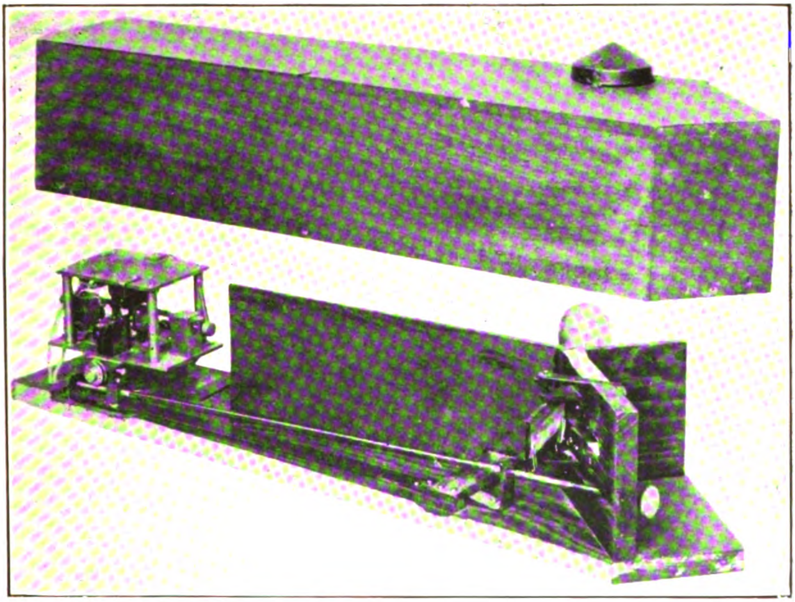

FIGURE 2—Model of Instrument for Visual Reception

The first recorder constructed was designed to receive signals at a speed not greater than 25 words per minute.

The photographic record was obtained by projecting the image of a straight filament lamp from the mirror of the galvanometer onto a cylindrical lens and focused by the same mirror to a small dot of light on a specially prepared sensitized paper tape. When the mirror was set into vibration by the incoming signal, this spot of light moved rapidly back and forth across the tape, its width of vibration depending on the strength of the signal. As the tape was moved across the point of exposure, the rapid vibration of the light resulted in the dots and dashes appearing as solid blocks. Figure 4 is a photograph of the first model constructed for photographically recording radio signals.

By means of a spring motor connected with suitable gears and friction pulleys, the tape was made to move not only past the point of exposure, but thru a tube of developing solution, and then thru a tube containing the fixing bath, from which it passed into the receiving basket.

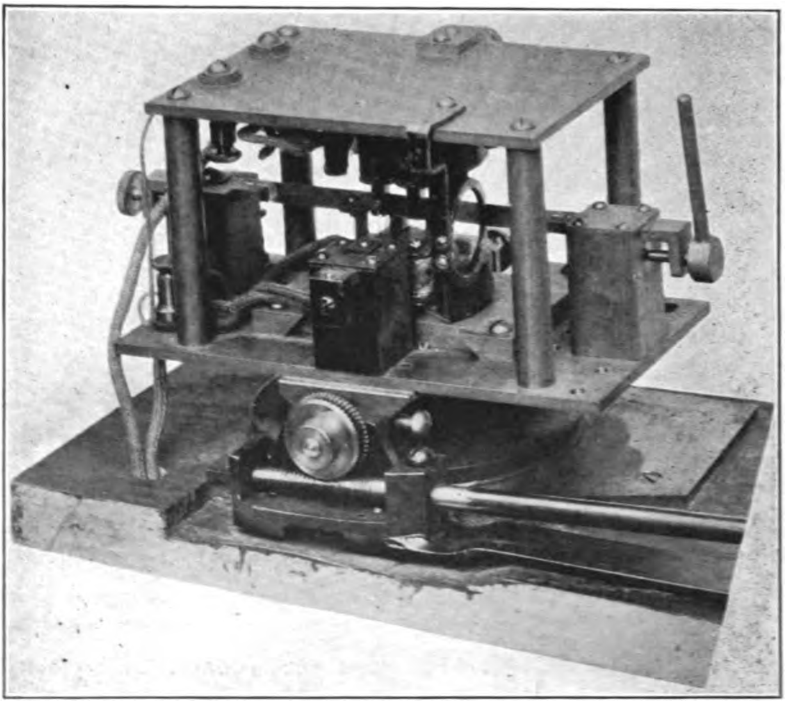

FIGURE 3—Galvanometer Used in Completed Model for Visual Reception

In this model, a second mirror was mounted on the shaft at a slightly different angle from the other, so that an image of the lamp filament could also be projected on a ground glass, thus permitting the operator to adjust the instrument properly and supervise its operation. A pair of telephones were also attached so that it was also possible to hear the signals. Means were provided for using rolls containing 200 feet (61 m.) of tape each, upon which about 2,000 words could be recorded. A special sensitized paper tape was used, which was very sensitive and capable of being developed in less than ½ minute, by using a special developing solution.

Figure 5 shows the arrangement of the galvanometer and the lighting system.

Figure 6 is a view of the galvanometer used in this instrument, in which are shown the two mirrors and the adjusting mechanism. In order to show the remarkable selectivity of this instrument the following experiment was made.

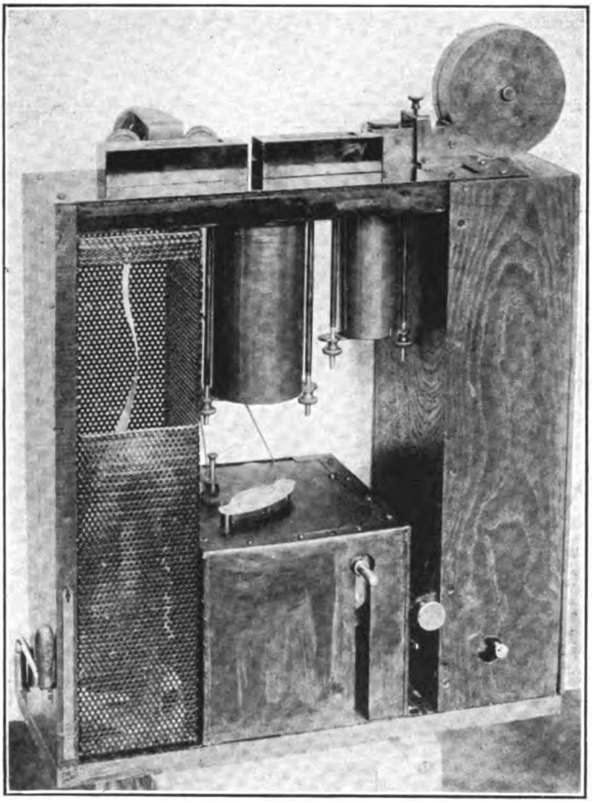

FIGURE 4—Photographic Recording Device for Radio Telegraphic Signals—Front View

Two separate messages were impressed upon the receiving circuit simultaneously from two different sources. One was at an audio frequency of 1,000 cycles and the other at 1,025 cycles. While these messages were coming in, the instrument was first tuned to 1,000 cycles and a portion of one message recorded; it was then tuned to 1,025 cycles and a portion of the other message recorded. It is obvious that if two instruments had been available both of these messages could have been received at the same time. Figure 7 is a reproduction of these signals and shows no interference between the two messages. When listening by means of a telephone, it was impossible to separate one from the other.

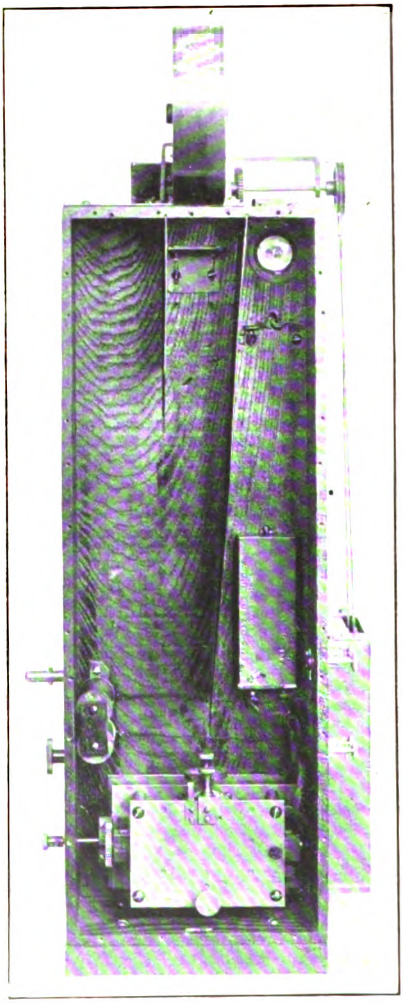

FIGURE 5—Photographic Recording Device for Radio Telegraph Signals—Showing Vibrating Unit Mounted in Box

Altho the instrument just described was very selective and well adapted to record signals under conditions for which it was designed, it was not suitable for recording the weak signals coupled with the static ratio that is generally encountered in trans-Atlantic reception. This was made apparent while making a demonstration with the model just described at the Bureau of Standards, Washington, D. C., in the presence of radio experts

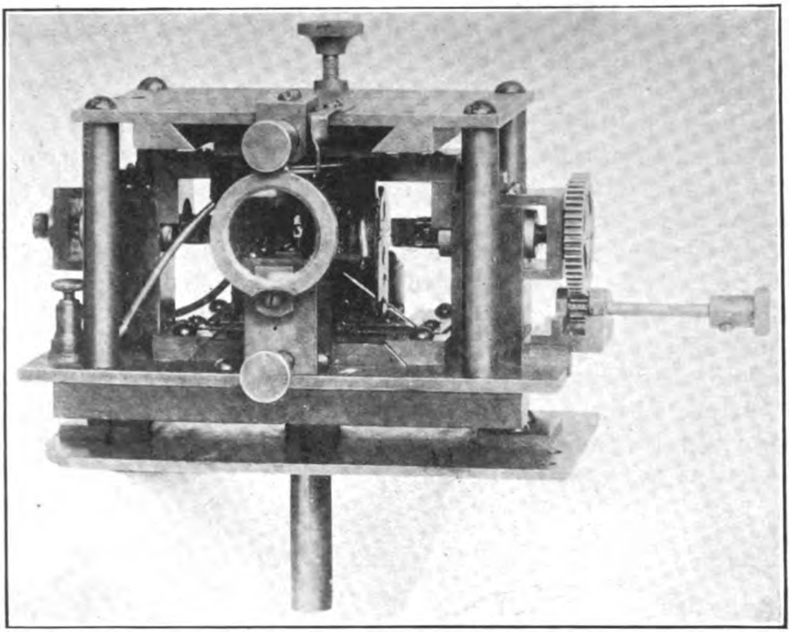

Figure 6—Vibrating Unit Used in Photographic Recording Device for Radio Telegraphic Signals—Front View

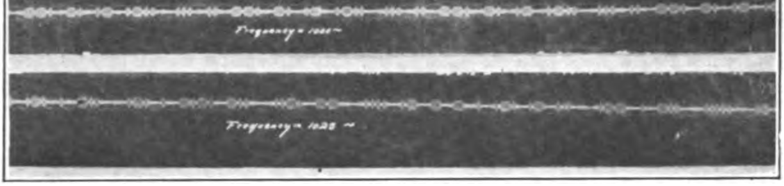
MULTIPLEX RECEPTION
Recording two messages impressed simultaneously upon same receiving circuit
Frequency = 1000 ~
Frequency = 1025 ~

Figure 7

of the Army and Navy. At this time messages were successfully recorded from several radio stations, but when an attempt was made to record signals from across the Atlantic it was found that the static interference was sufficient to render a large part of the record unreadable.

Steps were then taken to improve the instrument by making it more sensitive and less affected by static or strays.

In order to make the instrument more sensitive, the small shaft carrying the mirror was re-designed so as to eliminate the lost motion at the terminals of the shaft where they entered the jewels. This was done by constructing a shaft with a knife edge running its entire length, on which the mirror was mounted. This edge fitted into the apex formed by placing two rectangularly shaped jewels at right angles to each other, the shaft being held firmly in this position by the action of a small magnet. The thick side of the shaft was connected to the reed by means of a wire, the vibrations of the reed causing it to rock to and fro. Only one mirror was cemented to the shaft, an extra lamp being provided to produce the other image. Figure 8 shows the details of this construction.

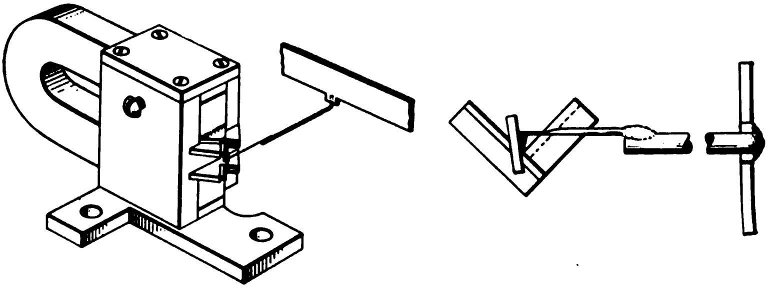

FIGURE 8—Showing Construction of the Vibrating Element

It was found also by changing the coils so as to encompass the vibrating strip instead of being wound around the pole pieces as in the type previously described, that greater sensitivity could be obtained. Figure 9 shows this construction. The galvanometer was placed at double the distance from the sensitized tape, which also produced the effect of increasing its sensitivity two-fold. In fact, the total increase in sensitivity in this model over the first was at least ten times. A signal which can be said to have an audibility of about 40 can be easily recorded.

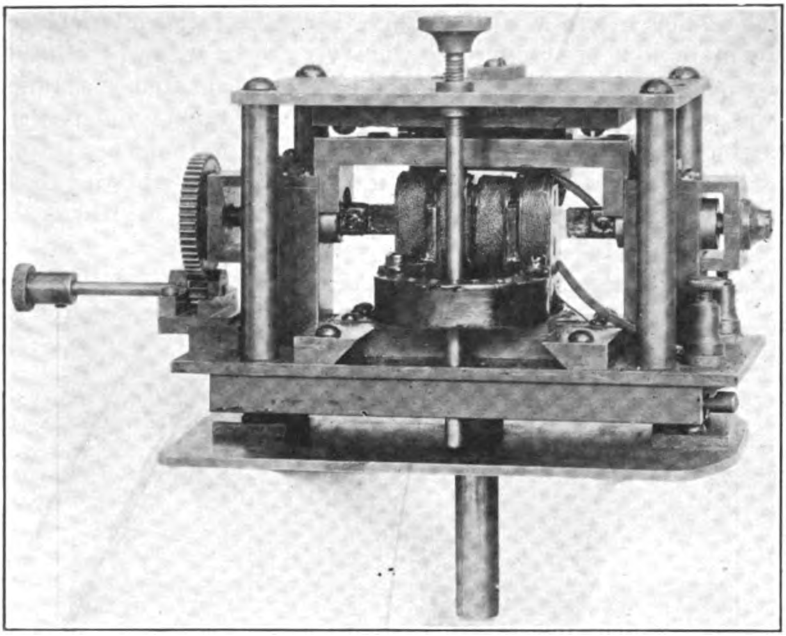

FIGURE 9—Vibrating Unit Used in Photographic Recording Device for Radio Telegraphic Signals—Back View

The problem left unsolved was simply to make the changes necessary to prevent its responding to static or strays and still to be left sensitive to signal impulses.

After reading my discussion on Dr. Austin's paper* in which I submitted several sample records of static made with my recorder, I am afraid I shall have difficulty in persuading the readers of this paper that I was very successful, but I can assure them that altho static conditions can still be such as to render the record unreadable, a considerable improvement was made. As stated before, the galvanometer, when tuned to 1,000 cycles, did not readily respond to static or strays, but it was found by experiment that when the natural period of the vibrator was above 1,500 cycles, the tendency to respond to static impulses was much less. This is very clearly shown in Figure 10. This figure shows signals recorded under exactly the same conditions except that the natural periods of the vibrator is adjusted first to 1,200 cycles, then to 1,500 cycles, and finally to 2,000 cycles.

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* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 8, number 5, October, 1920, page 408.

The 1,200 record was unreadable because of the interference by static, but no interference whatever can be seen when tuned to 2,000 cycles. It was also found by experiment that less static was recorded if a closed electrical circuit containing inductance and capacitance, commonly called a tone or frequency trap, and accurately tuned to the natural period of the vibrating reed was connected in parallel with the galvanometer. A great deal, however, depended on the construction of the tone trap. It was found that in order to prevent a decrease in signal and otherwise to obtain the best results, the capacitance should not exceed one or two-tenths of a microfarad for a frequency of 2,000, and also that the resistance of the inductance circuit should not be more than 40 ohms.

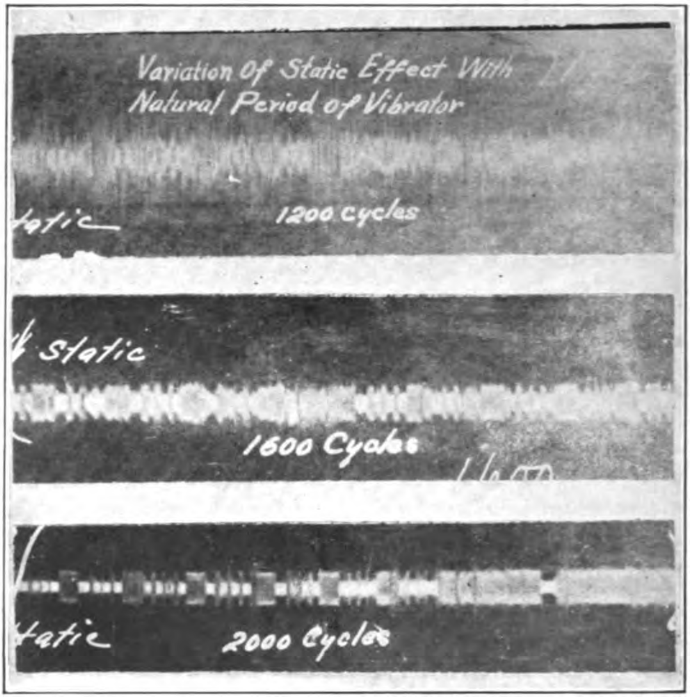

Figure 10

An instrument embodying these improvements, also designed to record at a maximum speed of about 35 words per minute, was then constructed, a small electric motor being used to pull the tape thru the machine. Figure 11 is a photograph of this model. With this instrument messages were successfully recorded at the then Naval Radio Station of Belmar from Nauen, Germany; Lyons, France; Carnarvon, England; Rome, Italy; San Diego, California; Pearl Harbor, Honolulu; and several other points.

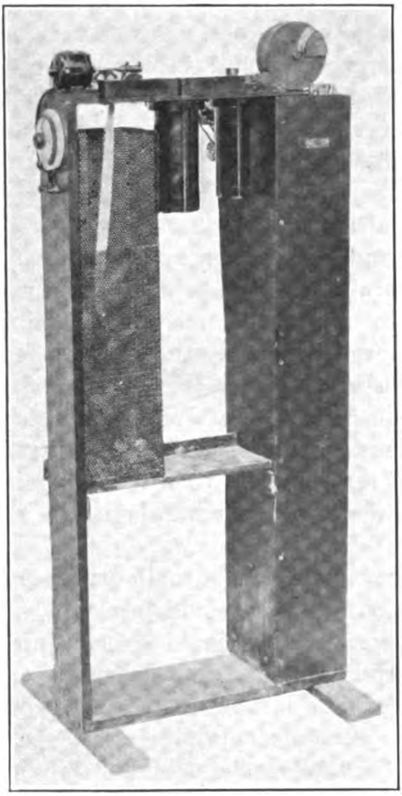

FIGURE 11—Second Model of Photographic Recorder

If my memory serves me right, it was during the year of 1899 that my attention was called to the art of "wireless" telegraphy by reading in the "Scientific American," a description of the first demonstration conducted by Mr. Marconi in this country, when he reported the result of the International Yacht Races off Sandy Hook.

At that time, and for a considerable time afterward, the dots and dashes were recorded on a paper tape. In this respect a similarity exists between Marconi's apparatus and the one here described. It did not, however, meet the present day requirements of speed.

Just why it was not practical to record at a speed greater than 12 or 15 words per minute with the apparatus used by Marconi, was very forcefully impressed upon me during the ensuing year while trying to duplicate the achievement with the limited means at my command. It was very easy to set a bell to ringing or even to adjust the coherer to obtain single taps, but perhaps there are some who can remember how easy it was to record the dots and how hard it was to adjust the system so that a dash did not look like a series of dots. The mere fact that the armature of the recording relay had a considerable mass prevented it from responding to the rapid action of the decohering hammer, and placed a low limit on the speed of reception. A little later the auto-coherer, and electrolytic and crystal detectors came into use making reception possible by telephone and thereby increasing not only the speed of reception, but the range of transmission. Under these conditions from 25 to 30 words per minute could be received. By using later types of keys and automatic devices the speed of transmission again exceeded that of reception, so then it was again a problem for the engineers to design a receiving device to meet the requirements.

In the early days of radio, the main question was not so much the speed at which a station could transmit, as it was the distance to which the messages could be transmitted. Now that we are able to send round the world, if necessary, the principal thing that concerns us is how many words or letters can be transmitted and received accurately per minute.

While in the photographic recorder previously described, the depth of the tubes containing the developer and fixing bath, the tape driving system, and the small candle power of the light used, limited the recording speed of this instrument to about 35 words per minute, the galvanometer itself was capable of recording several hundred words per minute. This feature will be referred to in another part of this paper.

The next model constructed was by far the longest step taken toward the development of a practical machine for commercial use. I will omit a detailed description of this instrument, except to say that it was designed to record at least 200 words per minute, and the tape, besides being simply developed and fixed, was also washed and dried before leaving the machine. The roll contained 1,000 feet (305 m.) instead of 200 feet (61 m.) of tape, thus permitting over 10,000 words to be recorded without re-loading. This model was taken to the Navel Radio Station at Otter Cliffs, Bar Harbor, Maine, in order to test the operation of the instrument when used in actual commercial service and for the purpose of receiving from European stations at high speed. It was soon made very apparent, however, that the words "high speed" did not mean 200 words per minute to the radio operators in Europe; even 100 was considerably beyond their limit. By repeated tests and numerous adjustments of the sending relay, it was found practical for the station at Lyons, France, to transmit at a speed of about 50 words per minute. This was, at least, considerably better than 20, the average speed of ear reception.

During the winter of 1918 and 1919 the traffic from Lyons was quite heavy; and 3,000 to 12,000 words daily, at approximately 50 words per minute, were recorded with this model.

An instrument was then designed for commercial use, of which several were made and are now in use at several trans-Atlantic receiving stations. Figure 12 is a photograph of this instrument.

These machines are capable of recording signals at a maximum speed of 200 words per minute, but during a series of special tests, over a distance of a few miles, satisfactory results were obtained at 250 words per minute. The speed of reception in this case was not limited by the galvanometer action, but by the time necessary for development, fixing, washing, and so on. There are four tubes shown in this figure of about 5 feet (1.53 m.) in length each, the first one at the right containing developer, the next the hypo solution, the third running water, and the last the drying tube. In order for the tape to be sufficiently developed, fixed, washed, and dried, at the maximum speed of reception, it is necessary for it to pass to the bottom of the tube. Figure 13 shows diagrammatically the method of exposure and the manner in which the tape is fed thru the machine. Arrangements are made whereby the pulleys a_1, a_2, a_3, and a_4 can be made to enter the tubes automatically to any desired depth, this depth depending upon the speed at which the signals are being recorded. In order to facilitate the threading of the tape, the traveling pulleys can be raised to the top of the tubes. The driving pulley at (*b*) causes the tape to move across the point of exposure at (*c*); it is then pulled by means of the friction clutch pulley at (*d*) thru the rest of the system. The mirror (*e*) permits the record to be inspected as it leaves the hypo bath. The roller (*f*) removes the surplus water in order to facilitate the drying of the tape. (*d*) is a blower by which air is driven over a heated coil (*l*) up thru the tube, thus drying the paper before entering the basket.

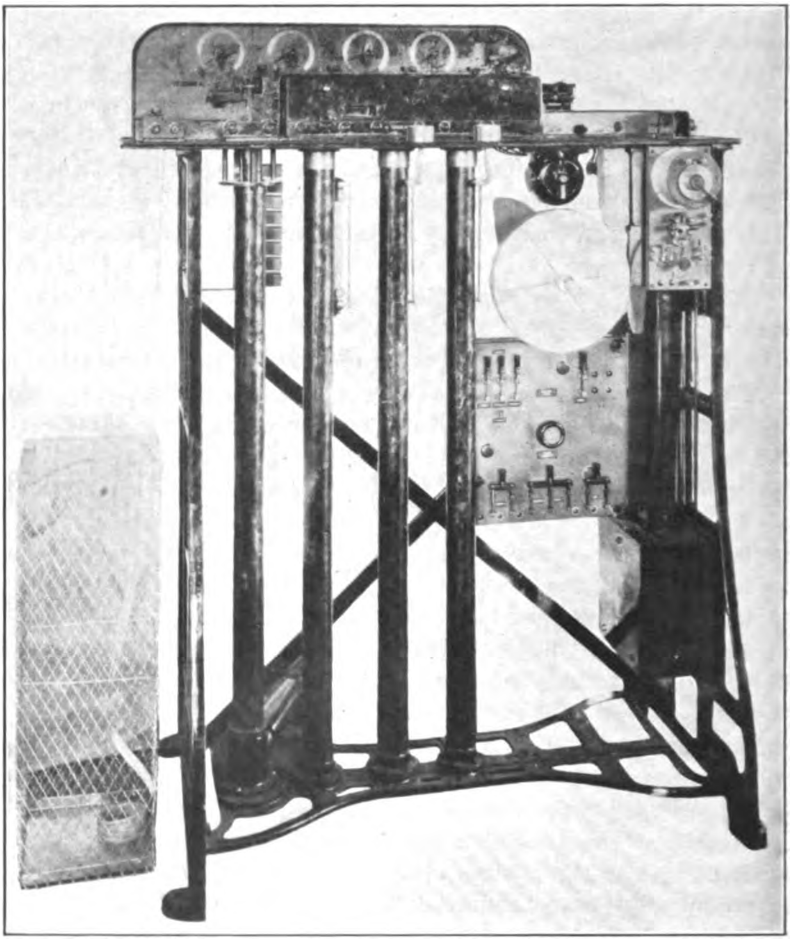

FIGURE 12—Visual and Photographic Receiving Device—Front View

Figure 14 is a diagrammatic view of the way in which the traveling pulleys are moved up or down in the tubes and also the method by which their depth is automatically determined.

Referring again to Figure 12, these four pulleys are clearly seen at the top of the instrument. The control relays are shown near the drying tube. The driving motor is shown just above the roll holder. The speed of this motor can be controlled by the rheostat located on the power panel below. Besides this control, arrangements are provided for three speeds by means of suitable gears—the control lever being shown at the top and near the right of the instrument. This permits the tape feed

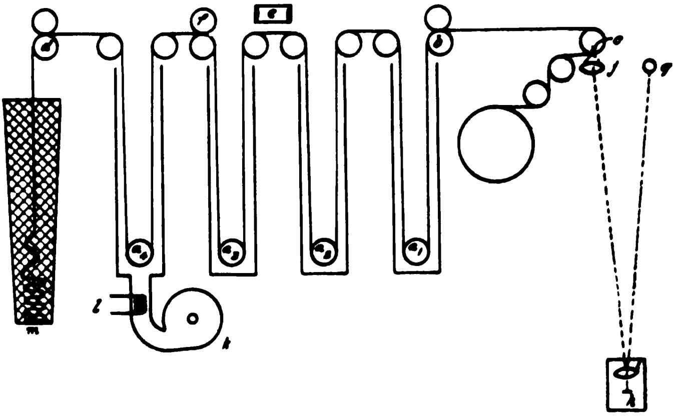

FIGURE 13—Showing Diagrammatically How Tape Is Fed Thru Machine

to be regulated so that the proper amount of space is given to each letter whether recording at normal rate or at the maximum speed of reception. Rolls of tape having a standard length of 1,000 feet (305 m.) are used, the holder being located just below the motor. An indicating device is provided to show the amount of tape in the holder. On the radio panel, located at the upper right hand corner, is located a condenser which is in parallel with the oscillator condenser and is for the purpose of controlling the audio frequency necessary for the proper operation of the galvanometer, the standard frequency adopted being 2,000 cycles. On this panel a telegraph key also is located by which any desired notation may be made on the edge of the tape, thru which the beam of light is projected on to its edge, resulting in dots or dashes, depending upon the operation of the key. An example of this will be shown later. On this panel are also located the binding posts to which a telephone is connected in order that the signal being recorded may also be heard.

As before described, the vibration of the galvanometer may be noted by means of an image of a light filament projected on to a panel of ground glass. The opening thru which this line of light is observed is located at the upper extreme right hand corner of the picture. Not only does this give the operator an opportunity to note the character of the signals being recorded, but it also enables him to make the proper adjustments as to frequency, position on tape, and so on.

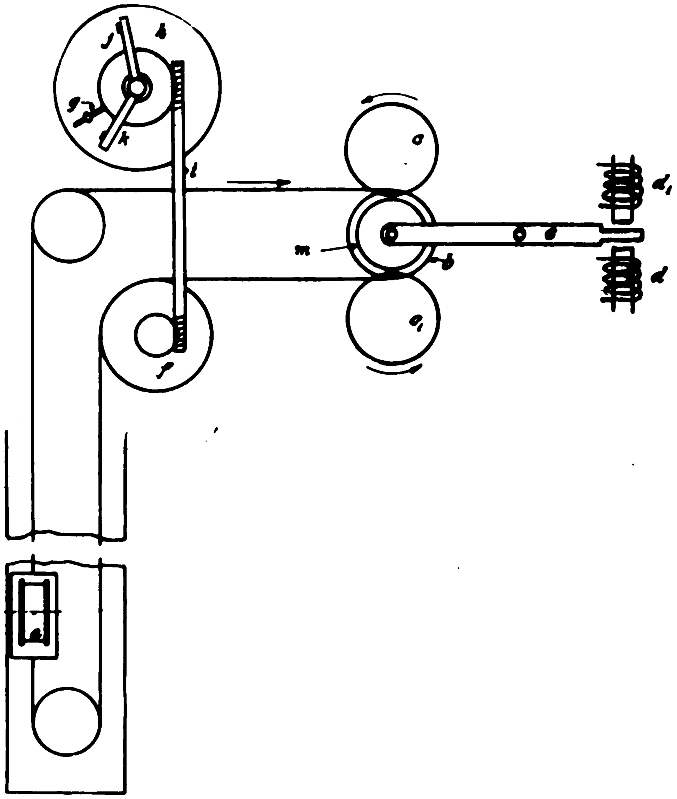

FIGURE 14—Diagram of Depth Control System

Figure 15 is a rear view of the instrument. In this picture, the glass gauges are shown by means of which the height of the solution in the tubes is indicated. The portion at the top, showing the controlling magnets and other gear, is protected by a suitable covering case, when the machine is in operation.

Figure 16 is a diagram showing the relative position of the reading and observation lamp and the galvanometer. The galvanometer as finally designed and built was considerably more massive than the former types. This made it less liable to get out of adjustment, and in general more stable and less sensitive to extraneous vibrations. Figure 17 is a photograph of the instrument as it appears when in use. It is protected with a dust-proof covering case. The high rate of speed at

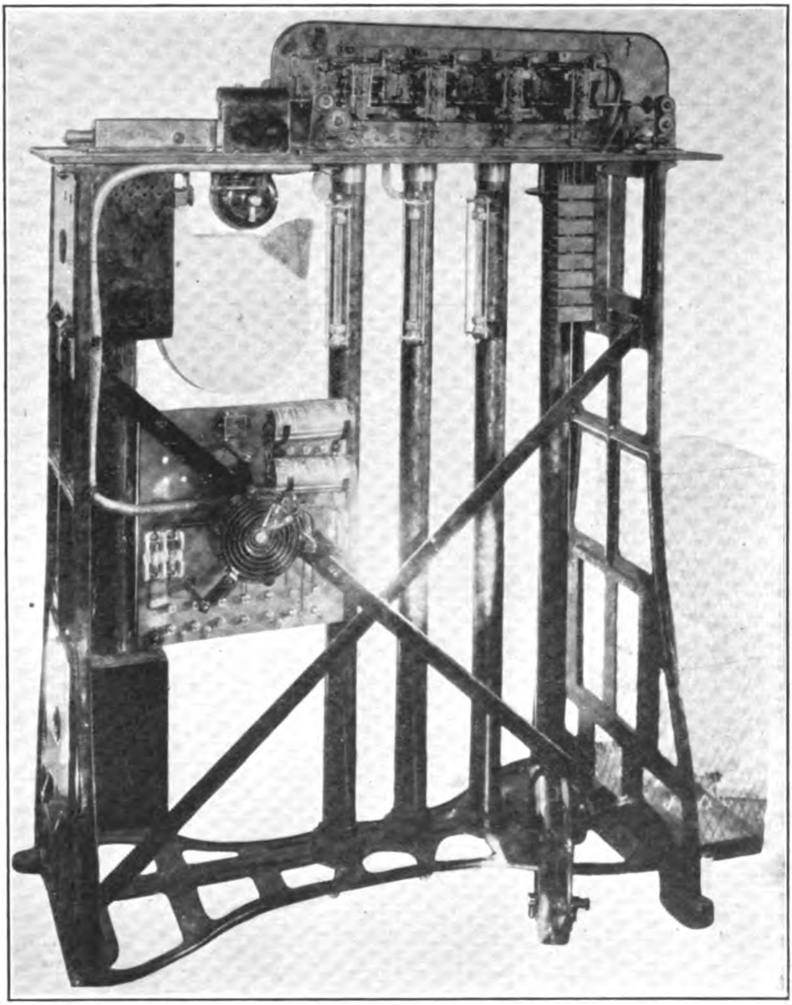

FIGURE 15—Visual and Photographic Receiving Device—Back V ew

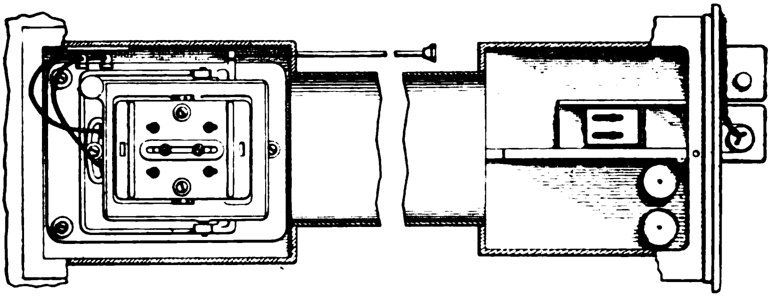

FIGURE 16—Diagram Showing Relation Between Lighting System and Galvanometer

which the galvanometer is capable of recording is perhaps the most spectacular feature of the instrument, even tho it may not be the most important. Laboratory tests have shown that it will record successfully as high as 600 words per minute. In fact, even higher speeds have been obtained. It is somewhat interesting to note the action of the galvanometer when recording 100 words per minute (see Figure 18). In order to check the speed at which these signals are received, the following calculations can be made: 50 units equal an average word at 5 letters in the Continental Code. A dot equals one unit at 100 words per minute. 5,000 units equal 1 minute, or 83.4 units per second.

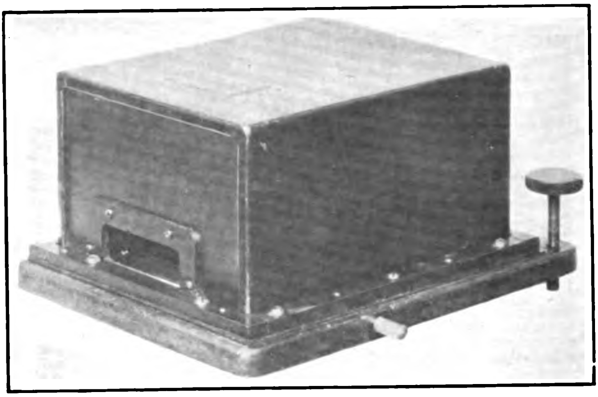

FIGURE 17—Galvanometer for Visual and Photographic Recorder (Asse ed View)

The galvanometer reed vibrates at 2,000 cycles per minute.

2,000 divided by 83.4 equals 24, and if we should take the trouble to count the vibrations in the dots here shown, we would find them equal to 24.

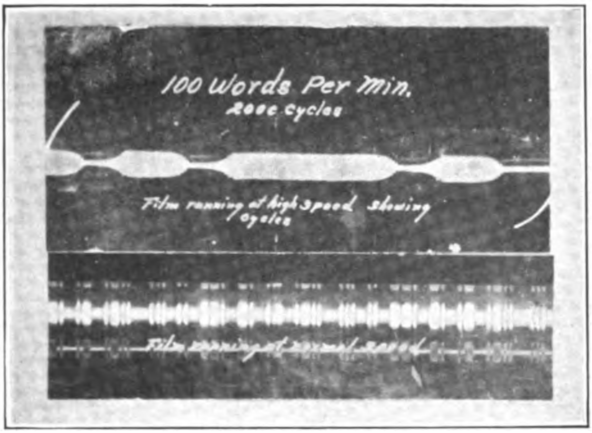
100 Words Per min.
2000 cycles
Film running at high speed showing cycles
Film running at normal speed

FIGURE 18

The principal item of interest connected with this picture however, is the fact that only 4 cycles are necessary for the signal to reach full amplitude. This means that the speed of the incoming signal can be increased to 500 words per minute and still be perfectly recorded. The lower line shows the signals as they appear on the tape in the regular way. Figure 19 shows high speed signals from 300 to 600 words per minute. It is

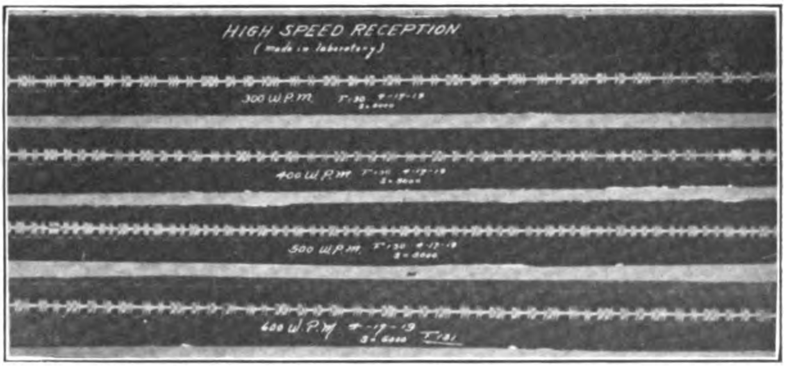

FIGURE 19

needless to say that these signals were produced in the laboratory within a few feet of the machine, but serve to show that the instrument would record satisfactorily at these speeds. Figure 20 shows records made by actual radio signals sent at high speed.

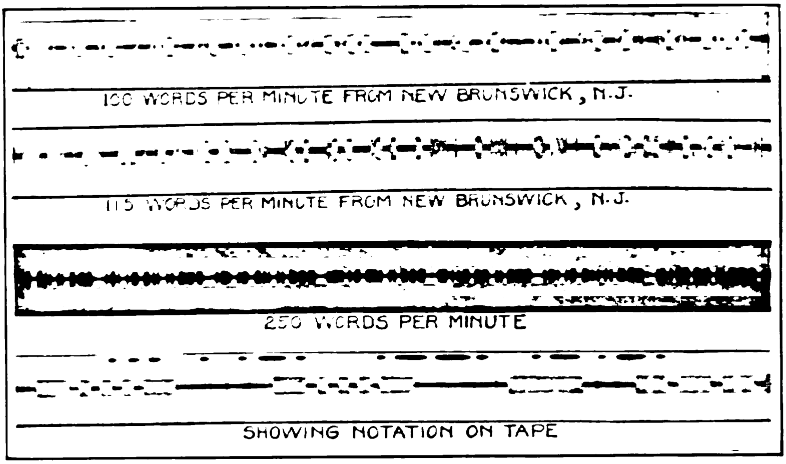

Figure 20

The two first records made were transmitted by the Alexanderson alternator from New Brunswick, New Jersey at 100 and 115 words per minute, respectively, and recorded in the General Electric Company's Laboratory at Schenectady, New York. The third record shown was also recorded in the laboratory from a small power station about three miles away (5 km.) at 250 words per minute. The lower record is made simply to show the appearance of the notations on the edge of the tape, made by means of the key on the radio panel of the machine as previously described.

One of these instruments has been in use in the Navel Radio Station at Otter Cliffs, Bar Harbor, Maine, for the past three years. During one of my visits within the past year or so, more than 100,000 letters or the equivalent of 20,000 five-letter words were recorded from Norway within a period of twelve hours at an average rate of 60 words per minute.

The lower portion of Figure 21 is a photograph of a piece of the record taken that day.

All the messages taken during the entire run were complete,

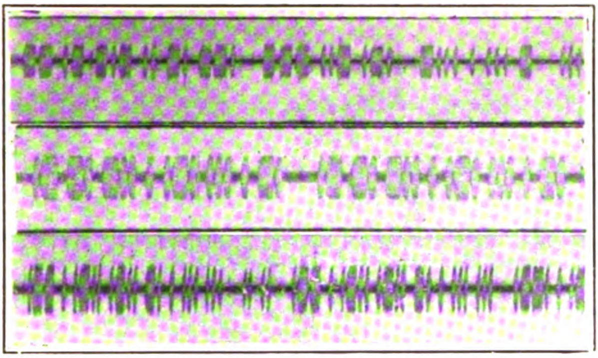

FIGURE 21—Signals Recorded By Visual and Photographic Recorder

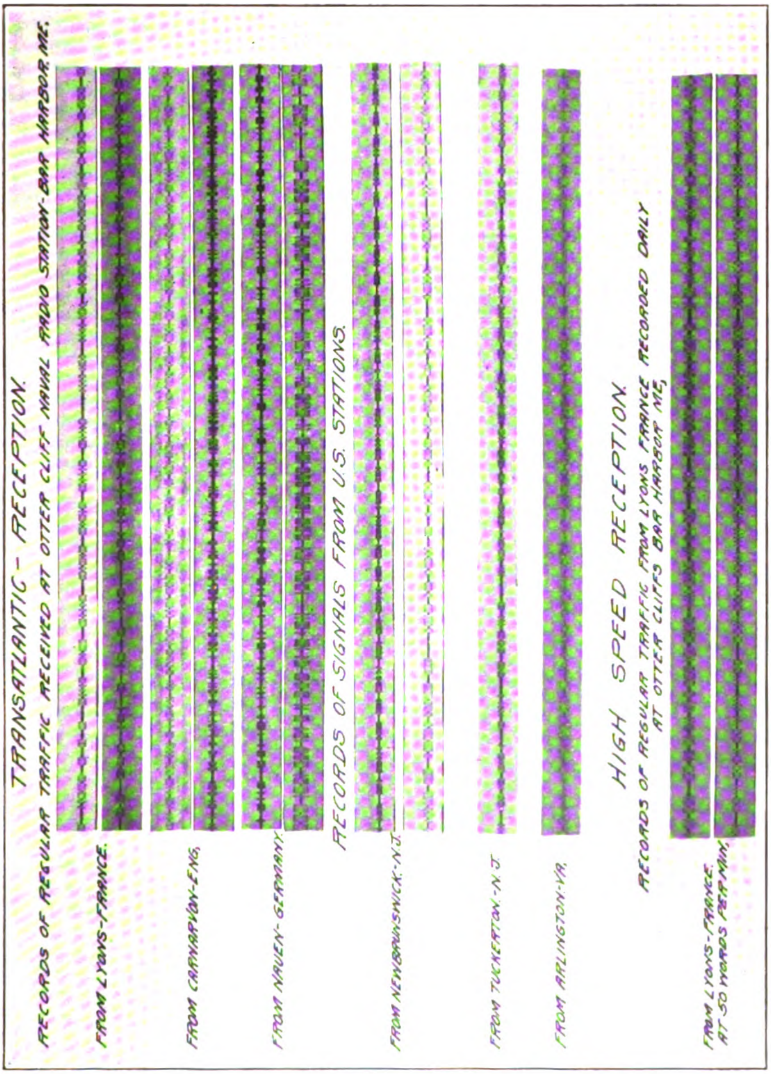
TRANSATLANTIC- RECEPTION.
RECORDS OF REGULAR TRAFFIC RECEIVED AT OTTER CLIFF NAVAL RADIO STATION- BAR HARBOR ME.
FROM LYONS-FRANCE.
FROM CARNARVON-ENG.
FROM NAUEN-GERMANY.
RECORDS OF SIGNALS FROM U.S. STATIONS.
FROM NEWBRUNSWICK-N.J.
FROM TUCKERTON-N.J.
FROM ARLINGTON-VA.
HIGH SPEED RECEPTION.
RECORDS OF REGULAR TRAFFIC FROM LYONS FRANCE RECORDED DAILY AT OTTER CLIFFS BAR HARBOR ME.
FROM LYONS-FRANCE. AT 50 WORDS PER MIN.

FIGURE 22—Exhibition Record of Radio Signal Records

and no repeats were necessary. The upper record in the figure is a part of a message from Nauen, Germany. Figure 22 is a photograph of several records made at the Otter Cliffs Station.

In Figure 23 is shown the way in which the recorder is ordinarily connected to the receiving system. The correct pitch or note is obtained by varying the heterodyne or local oscillator until the maximum amplitude of vibration is obtained.

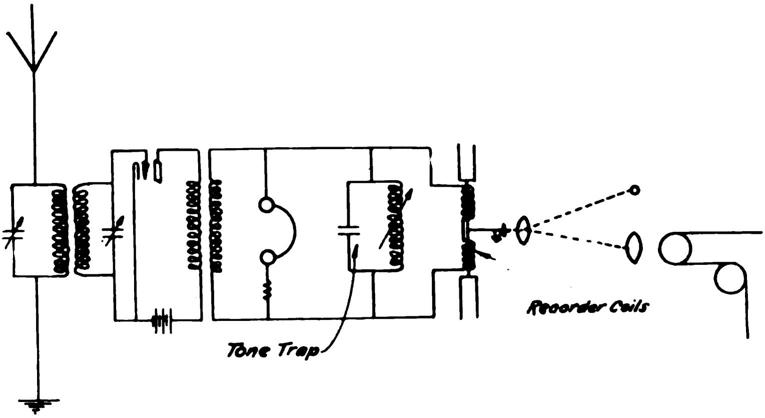

FIGURE 23—Diagram Showing Manner in Which Recorder Is Connected to the Receiving System

SUMMARY: The development of a visual and photographic recorder of the tuned vibrator type is described. The most recent forms of the instrument, together with its receiving speed possibilities and behavior toward stray disturbances, are discussed.

DIGEST OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued August 23, 1921—October 25, 1921

By
John B. Brady
(Patent Lawyer, Ouray Building, Washington, D. C.)

The object of this section in the Proceedings of The Institute of Radio Engineers is to make available in convenient form for research engineers and others interested, brief information on radio patents which are issued each week by the Patent Office. The rapid developments in this art emphasize the importance of radio research engineers being familiar with patent literature, to eliminate, as far as possible, the duplication of effort in research. It is not the purpose of this section to explain radio inventions fully, but merely to indicate the general nature of the patents in order that those of particular interest to individuals concerned with certain problems may be selected, and complete copies of the patents obtained for study. Copies of the patents may be secured at ten cents each by communicating with the Commissioner of Patents, Washington, D. C.

1,387,885—William R. Davis, of Minneapolis, Minnesota, issued August 16, 1921, filed March 9, 1918. Assigned to The William Hood Dunwoody Industrial Institute.

Radio Signaling Apparatus for the teaching of radio signals to students in a classroom. The equipment comprises an inductor which is rotatably driven adjacent to a plurality of magnets connected in separate transmitter and receiver circuits for use by individual students or groups of students. By varying the speed of the inductor, different frequencies of signals may be obtained to assimilate the conditions in radio reception.

1,388,336—Earl C. Hanson, of Washington, District of Columbia, filed February 25, 1919, issued August 23, 1921.

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*Received by the Editor, November 7, 1921. While great care has been taken in the preparation of these Digests, The Institute of Radio Engineers assumes no responsibility for their correctness or completeness, or for possible omissions of particular patents.—Editor.

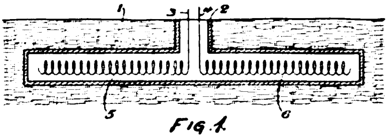


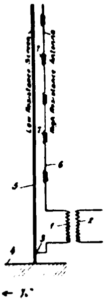
Fig. 1

Number 1,388,336—Underground and Submarine Antenna

Underground and Submarine Antenna, wherein the antennas are formed by a pair of extended inductances connected to radio signaling apparatus. The inductances are buried horizontally in the earth and have their ends electrically free.

1,388,441—Michael I. Pupin, of Norfolk, Connecticut, and Edwin H. Armstrong, of Yonkers, New York, filed October 1, 1915, renewed January 14, 1921, issued August 23, 1921.

Fig. 1,



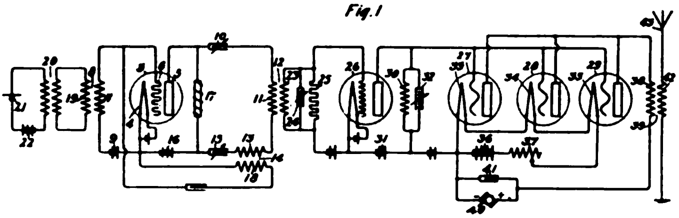
Number 1,388,441—Multiple Antenna for Electrical Wave Transmission

Multiple Antenna for Electrical Wave Transmission, screened against the disturbing effects of electrical impulses of short duration. A receiving antenna, of such high resistance as to screen the system effectively against disturbing electromagnetic waves impressed upon the conductor, is employed in inductive relation with a low resistance antenna which serves as a screen protecting the high resistance antenna against electromagnetic pulses of short duration.

1,388,450—Edwin H. Colpitts, of East Orange, and Harold De Forest Arnold, of Maplewood, New Jersey, Assigned to Western Electric Company, filed September 3, 1915, renewed January 13, 1921, issued August 23, 1921.

Transmission of Intelligence by radio telephony. Radio

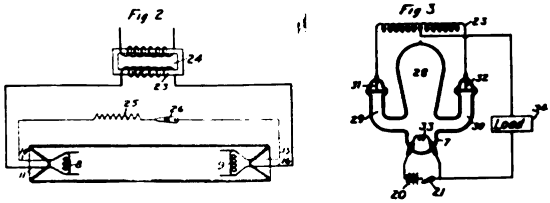
Fig. 1



NUMBER 1,388,450—Transmission of Intelligence

frequency oscillations of feeble amplitude are generated at the transmitter and these feeble oscillations modulated while in their feeble state. These feeble modulated oscillations are then amplified both in voltage and amperage to sufficient power for effective trsnsmission.

1,388,793—Wilfred T. Birdsall, of Montclair, New Jersey, filed January 5, 1917, issued August 23, 1921. Assigned to Westinghouse Lamp Company.

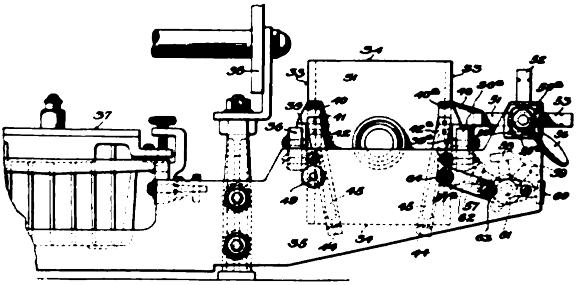


NUMBER 1,388,793—Vacuum Type Converter

VACUUM TYPE CONVERTER, wherein the discharge is not dependent upon an auxiliary heating current thru a filamentary cathode as is the case with the heated filament construction of the Fleming rectifier and the De Forest tube. The discharge is maintained by virtue of electron emission and operates in the absence of auxiliary means for maintaining one or more electrodes at an electron emitting temperature. The apparatus comprises two filamentary electrodes, means for supplying either a direct or alternating current across the electrodes and means for initially passing a heating current thru each of the electrodes until they are brought to an electron-emitting temperature. Having raised the electrodes to this temperature a bi-lateral current flow is established between them and this current flow maintains the electrodes at an electron-emitting temperature, the initial heating means being disconnected from the electrodes. Another feature of the apparatus is the provision of electrostatic shields, 22 upon the electrodes which prevent the localization of discharge upon restricted portions of the surfaces of either of the electrodes. Figure 3 shows the connections for delivering rectified energy to the load 34 from an alternating current supply 23.

1,388,834—Fritz Lowenstein, of Brooklyn, New Yok, filed January 19, 1918, issued August 23, 1921.

Fig. 1.



Number 1,388,834—Spark-Gap Apparatus

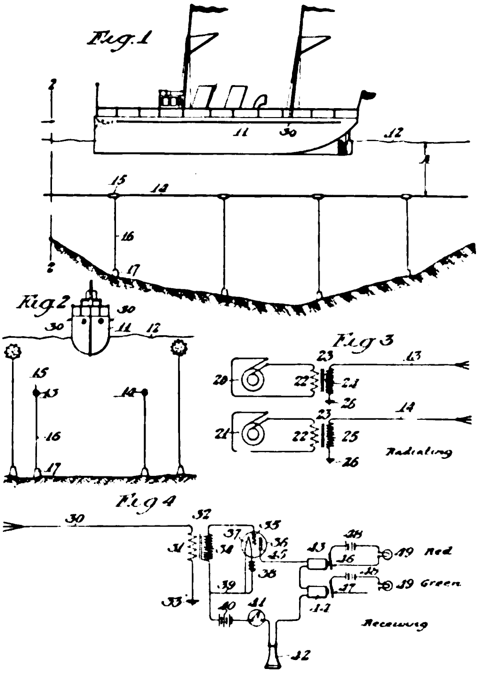
Spark-Gap Apparatus for use with quenched spark radio transmitters. The quenched gap is carried in a rack associated with the wave changer and condensers. The quenched gap unit comprises a pair of electrode members insulated from each other and having co-operating circular annular sparking surfaces disposed in parallel, closely spaced relation in combination with a bolt extending within the inner peripheries of said sparking surfaces, the bolt threading into one of said members and extending thru the other of said members but insulated therefrom and arranged to clamp the same in sparking position with the first-mentioned electrode.

1,388,936—Horace St. John de Aula Donisthrope, of London, England, filed April 28, 1920, issued August 30, 1921.

Radio Telegraphic and Telephonic Apparatus for portable operation. The receiver is made compact by its construction in the form of hinged sections similar to a book, with inductances in the opposite leaves. The apparatus includes a crystal detector, a condenser, telephone terminals and aerial and earth terminals. The inductances have their coupling varied by a change in the angular relationship of the hinged parts.

1,388,949—Earl C. Hanson, of Los Angeles, California, filed

June 4, 1918, issued to August 30, 1921. Assigned to Title Insurance and Trust Company.

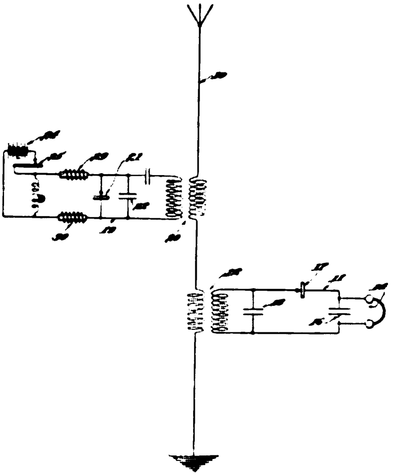


Number 1,388,949—Audio Frequency "Wireless" for Fog Signaling System

Audio Frequency "Wireless" Fog Signal System for the piloting of vessels into and out of port in fog or darkness. The apparatus is installed upon shipboard to enable navigation thru tortuous channels or harbors by visible or audible signals not dependent upon lighthouses or buoys. The system includes a cable laid in the channel way and energized from an audio frequency source. The apparatus on shipboard comprises a collector of the field of force emanating from the cable, a vacuum tube amplifier associated with said collector and means for observing the received energy. The patent describes both port and starboard visible signal lamps operated by the received energy and also telephone receivers operated by the amplified energy. The patent illustrates the position of a cable for piloting vessels in safety thru a mine field.

1,389,026—Vannevar Bush, of Chelsea, Massachusetts, filed

May 19, 1920, issued August 30, 1921. Assigned to American Radio and Research Corporation.



NUMBER 1,389,026—Radio Receiving System

RADIO RECEIVING SYSTEM for the reception of sustained oscillations which are broken up or modulated into groups at an audible frequency by periodically varying the resistance of the receiving circuit at audible frequency.

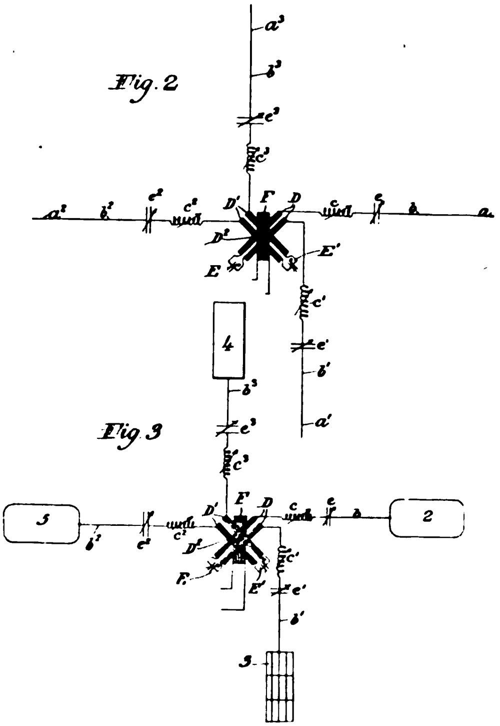
1,389,255—Leslie R. McDonald, of Montreal, Quebec, Canada, filed May 16, 1917, issued August 30, 1921. Assigned to William J. O'Leary, of Montreal, Quebec, Canada.

RADIO FREQUENCY ELECTRICAL OSCILLATION APPARATUS, comprising a construction of a combined capacity and inductance by which radio frequency energy is transferred from an oscillating circuit to a working circuit. Both the primary and secondary of the inductive coupling are open so that the coupling affords a large proportion of the capacity of the oscillation circuit.

1,389,351—Charles Howard Harvey, of London, England, filed May 7, 1918, issued August 30, 1921. Assigned to General Electric Company, Ltd., London, England.

MEANS FOR SUPPORTING ELECTRODES IN IONIC TUBES, comprising a spring mounting for the cathode. The vacuum tube casing is provided with a tubular socket of glass fixed within the vessel with a shoulder at the outer end of the socket. An anchor wire having a knob at its end passes slidably thru said socket and is engaged by the shoulder. The anchor wire is secured to a spring and the spring in turn supports the heated cathode.

1,389,800—Roy Alexander Weagant, of New York, N. Y., filed February 1, 1918, issued September 6, 1921. Assigned to Radio Corporation of America.



Number 1,389,800—Radio Signaling Apparatus

Radio Signaling Apparatus at a radio receiving station having a plurality of separated antennas tuned to the same frequency and adapted to receive horizontally propagated waves in a plurality of directions. Figures 2 and 3 show the antennas in the form of extended wires and plates or networks with means connected in the antenna circuits for the elimination of static disturbances.

1,390,288—John Hays Hammond, Jr., of Gloucester, Massachusetts, filed July 24, 1913, renewed January 24, 1921, issued September 13, 1921.

System for Controlling Moving Bodies by Radio Energy having at the transmitter means for emitting different frequencies and at the receiver a plurality of circuits respectively responding to the different frequencies. A commutator apparatus is arranged intermittently and automatically to connect the detector to any one of the receiving circuits and means synchronized with the commutator apparatus are provided for connecting the desired control circuits with the detector circuit.

1,390,883—Theodore W. Case, of Scipio, New York, filed April 5, 1918, issued September 13, 1921.

RADIANT-ENERGY DETECTING AND TRANSLATING DEVICE, embodying a normally oscillating circuit for indicating very slight changes in resistance in a predetermined circuit resulting from variations of intensity of light rays to which resistance is exposed.

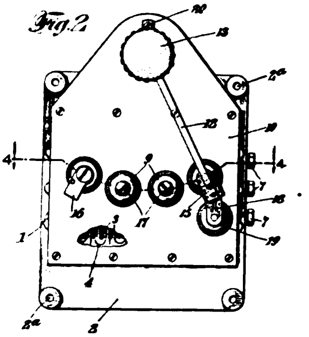
1,391,671—Horace St. John de Aula Donisthrope, of London, England, filed March 23, 1921, patented September 27, 1921.

THERMIONIC VALVE FOR USE IN RADIO TELEGRAPHY AND TELEPHONY, having hollow hemispherical plate and grid electrodes inverted over a looped filament. The advantages claimed for this arrangement are that the cathode stream is more uniformly distributed than when the ordinary plate type of electrode is employed and consequently disintegration is more uniformly distributed thereby increasing the life of the valve; and the arrangement also serves to damp down or eliminate microphonic disturbances or noises.

1,391,672—William Dubilier, of New York, N. Y., filed August 1, 1918, patented September 27, 1921.

ELECTRICAL CONDENSER, constructed of rectangular plates having one dimension substantially greater than the other and interleaved with larger rectangular insulating sheets of greater length than width. The novelty in this condenser lies in the construction of the stack. The side edge portions of the longer dimension of the condenser plates project alternately beyond the two longer sides of the dielectric sheets, the similarly projecting edge portions of the plates being connected together thruout their whole length to constitute the terminals for the condenser. The terminals are thus constructed to provide the shortest mean heat conduction path and the path of lowest mean resistance to the exterior of the condenser.

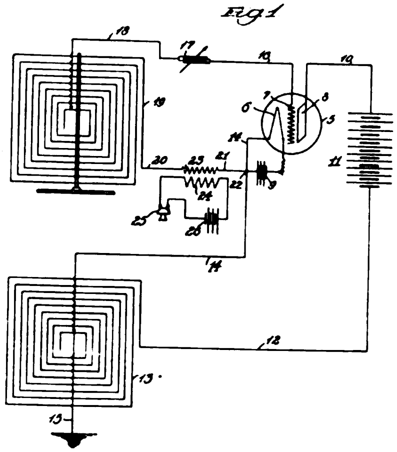
1,391,673—William. Dubilier, of New York, N. Y., filed March 7, 1919, renewed March 5, 1921, patented September 27, 1921. Assigned to Dubilier Condenser Company, Inc.



NUMBER 1,391,673—Antenna Shortening Device

ANTENNA SHORTENING DEVICE, comprising a plurality of condenser sections connected in series and tapped to different terminal posts arranged on a casing containing the condenser sections. A switch arm is provided movable over the terminal posts to connect in circuit the respective condenser sections in series with an antenna system to shorten the wave length to the desired value. A short-circuiting contact is provided whereby the series condenser may be entirely cut out of the antenna circuit.

1,391,855—Henry K. Sandell, of Chicago, Illinois, filed November 28, 1919, patented September 27, 1921. Assigned to Herbert S. Mills, of Chicago, Illinois.



NUMBER 1,391,855—Radio Transmitting System

Radio Transmitting System, employing a vacuum tube oscillator circuit having a loop antenna series connected in the input circuit of the oscillator and rotatably mounted and another loop antenna in series with the output circuit of the oscillator and arranged in proximity to the first mentioned loop. In the circuit illustrated in the patent the oscillator is modulated by a telephone transmitter connected in the input circuit.

1,393,018—Peter Cooper Hewitt, of Ringwood Manor, New Jersey, filed March 9, 1916, issued October 11, 1921.

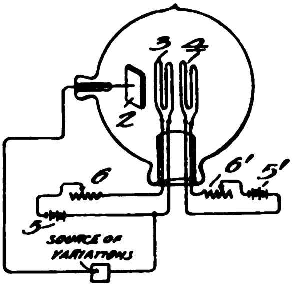


Fig. 3.

Number 1,393,018—Relay

Relay, comprising an evacuated vessel having an anode and a cathode therein, a battery connection for heating the cathode, a conducting member acting as a screen enclosed within the container and adjacent to the anode and means for heating the conducting member to a temperature having any desired relation to the temperature of the heated cathode. The tube is intended for amplifying electrical currents or translating variations and when used in such connection either the cathode or the screen may serve as the grid and the temperature of each may be controlled in such manner as to pass the desired amount of current in either direction.

1,393,077—William C. Brinton, Jr., of Kennett Square, Pennsylvania, filed October 8, 1918, issued October 11, 1921. Assigned mesne assignments to Philbrin Corporation.

Electrical Condenser, comprising layers of conducting material and layers of fibrous dielectric material of different degrees of hardness and compressibility, the harder and less compressible layers being of greater weight than the softer and more compressible layers. The entire condenser is enclosed in a tight-gripping casing compressing the layers in inter-relation.

1,393,594—William C. White, of Schenectady, New York, issued October 11, 1921, filed June 3, 1918. Assigned to General Electric Company.

Fig. 1

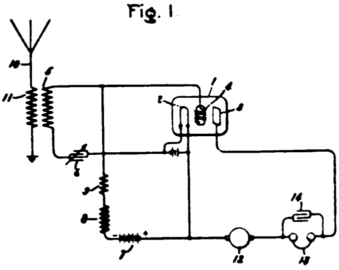
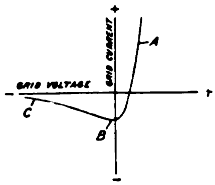


Fig. 2.



Number 1,393,594—Means for Producing Radio Frequency Oscillations

Means for Producing Radio Frequency Oscillations independently of any coupling between the grid and plate circuits of the vacuum tube oscillator. Under certain conditions in vacuum tube oscillator circuits, the current in the grid circuit may have a dropping characteristic, that is, as the voltage impressed upon the grid increases, the current in the grid circuit will decrease. With the proper conditions for operations, a circuit having current characteristics of the type described, may be so organized that oscillations will be produced therein, the essential condition for the production of oscillations being that the circuit shall contain capacity and inductance and that the resistance of the circuit shall be less than:

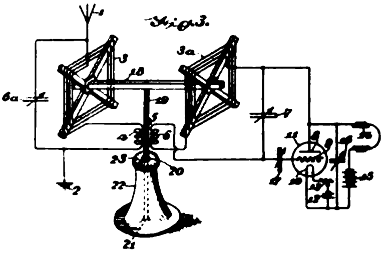
$$2\sqrt{\frac{L}{C}}$$

where L represents the inductance and C the capacity of the circuit. A resonant grid circuit is provided including a source of potential and adjusted so that the current in the grid will vary inversely as the applied potential over a given operating range of negative potential, the source of potential connected to the grid circuit being of such value that the normal potential of the grid is within the operating range, whereby oscillations will be produced in the grid circuit independently of any coupling between the grid and plate circuits.

1,393,602—E. A. Bayles and H. Higham, of Helsby, England, filed December 22, 1919, issued October 11, 1921. Assigned one-third to Ernest Richard Royston, Liverpool, England.

Electrical Condenser, comprising a plurality of condenser units, each unit made up of a series of spaced longitudinally aligned tubular condensers electrically connected and supported in removable racks within an oil container. The individual condensers are composed of coiled or folded laminas of paper and metal enclosed within cylindrical casings adapted to be threaded upon a vertically positioned frame carried on the removable rack submerged in the tank of oil.

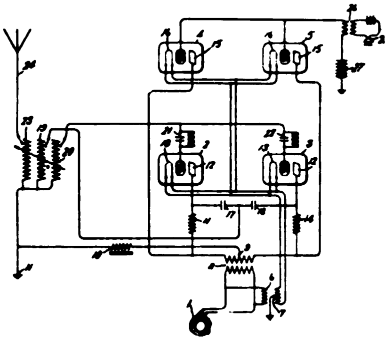
1,394,026—Lloyd M. Knoll, Philadelphia, Pennsylvania. Assigned one-fourth to Thomas Appleby, filed April 2, 1920, patented October 18, 1921.



Number 1,394,026—Radio System

Radio System for the location of the actual direction of a transmitting station as an improvement over systems which merely indicate the course of the signals, but do not differentiate between the true and converse directions. The system comprises the combination of an antenna circuit with a pair of rectangular loop collectors rotatably mounted and adapted to have their mutual coupling varied and connected in circuit as indicated in Figure 3.

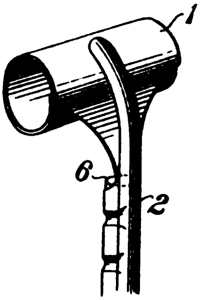
1,394,056—William C. White, of Schenectady, New York. Assigned to General Electric Company. Filed July 3, 1920, patented October 18, 1921.



Number 1,394,056—Signaling System

Signaling System, employing a vacuum tube oscillator and modulator. A source of alternating current of low frequency 1 is provided for supplying energy for the operation of the electron discharge oscillators 2 and 3 and the modulators 4 and 5. Current for heating the filaments of the oscillators and modulators is also derived from the source 1, being supplied to the filaments by means of the transformer 6, the middle point 7 of which is preferably grounded. Current for the operation of the oscillators and modulators is supplied to the plate circuits by means of the transformer 8, the secondary of transformer 8 being oppositely connected to the plate circuits of the oscillators 2 and 3 as well as to the plate circuit of the modulator 4 and 5. The plate circuits of the oscillators and modulators are all completed by a connection from the middle point 9 of the secondary of the transformer 8 thru a reactance 10 to ground 11.

1,394,090—Cassius Eugene Hiatt and William Joseph Davis, of London, England, filed May 19, 1919, patented October 18, 1921.

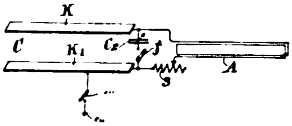


Number 1,394,090—Valve of Radio Transmission Systems

VALVE OF RADIO TRANSMISSION SYSTEMS, having a construction of plate which provides a high thermal conductivity between the plate and its support and which at the same time is of inexpensive manufacture. In the usual forms of vacuum tubes the plate is connected by electric welding to the upper end of a metal rod or post which at its other end is embedded in the glass support or stem, together with the electrical lead or conductor to which it is connected and which in turn passes to a terminal post of the tube. The electric welding process is usually carried out in an atmosphere of hydrogen in order to prevent oxidation and during the process the electrode absorbs the hydrogen and is therefore not gas-free. In the present construction the plate comprises a spirally-wound portion having an integral extension embedded in the glass support within the bulb, the extension supporting the anode and serving for the connection to the electrical lead and providing a path of high thermal conductivity in addition to its rigid supporting qualities.

1,394,560—Frederick A. Kolster, of Washington, District of Columbia, filed November 27, 1916, patented October 25, 1921.

FIG. 8.



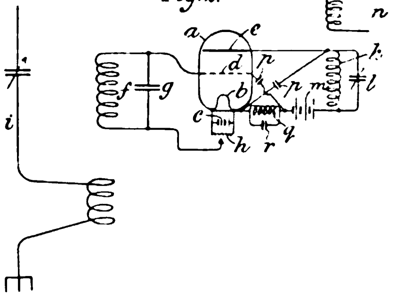
NUMBER 1,394,560—Apparatus for Transmitting Radiant Energy

APPARATUS FOR TRANSMITTING RADIANT ENERGY, comprising a closed radiating circuit including a coil inductance and a capacity made up of large separated areas and serving with the inductance as radiating elements. The circuit is placed in oscillation by coupling a source of either damped or sustained energy to the system modulated in accordance with the signals.

1,394,600—George Maurice Wright, of London, England. Assigned to Radio Corporation of American. Filed June 8, 1916, patented October 25, 1921.

RADIO TELEGRAPH RECEIVER, having a circuit for the reduction of noises due to atmospherics. The natural resistance of the antenna may be made of such a value as to damp the atmospherics while the effective resistance is reduced by the interaction of the incoming and outgoing circuits of a vacuum tube connected between the antenna system and the receiver. The filament of the vacuum tube is heated so slightly as to produce only very small magnification and to all practical degree no magnification of the signals, but sufficient to neutralize the antenna resistance for the weaker amplitudes of signals and yet render effective the resistance for the larger amplitudes of atmospherics.

Fig. 2.



NUMBER 1,394,600—Radio Telegraph Receiver

VOLUME 9 FEBRUARY, 1921 NUMBER 1

PROCEEDINGS
of
The Institute of Radio Engineers

APR 6 192
35

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GENERAL INFORMATION AND SUBSCRIPTION RATES ON PAGE 1

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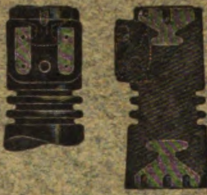
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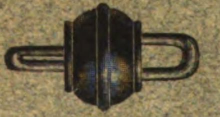
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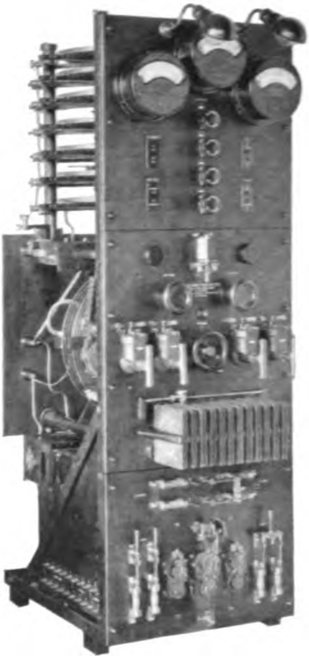

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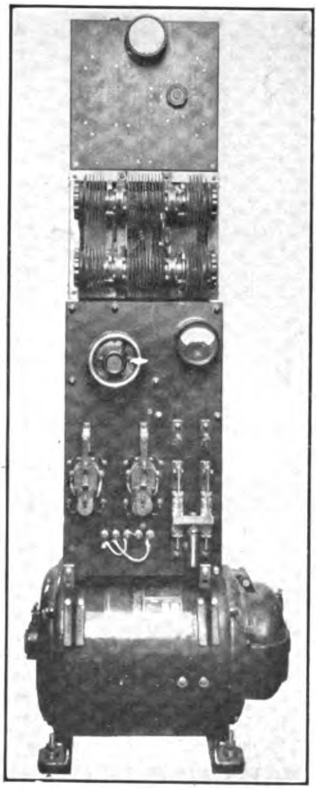

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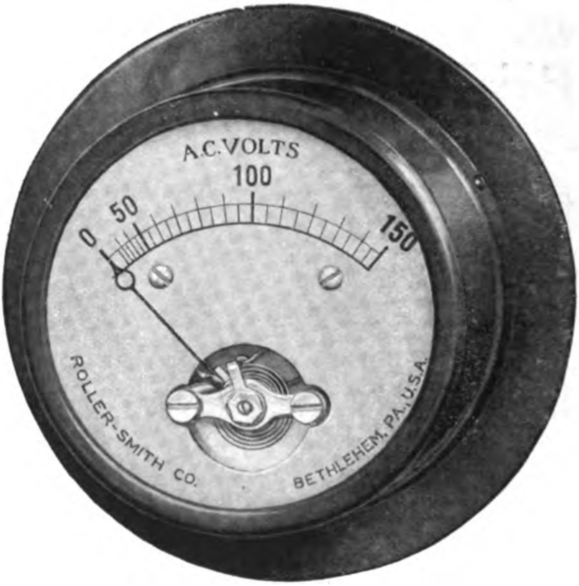

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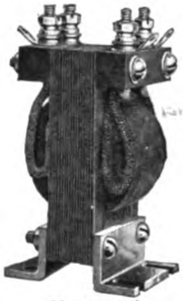

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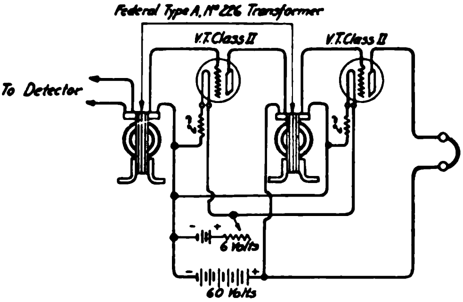

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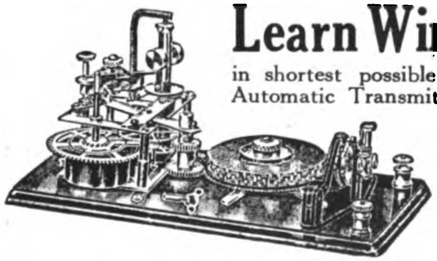

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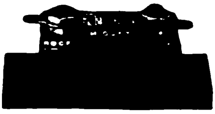

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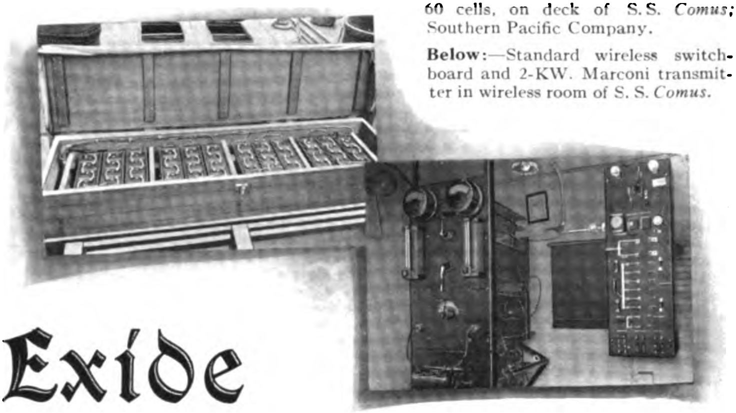

Left:—Exide Battery, Type MV 11, 60 cells, on deck of S. S. *Comus;* Southern Pacific Company.

Below:—Standard wireless switchboard and 2-KW. Marconi transmitter in wireless room of S. S. *Comus.*

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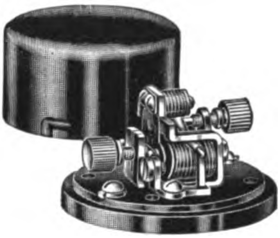

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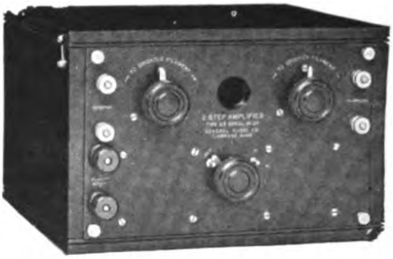

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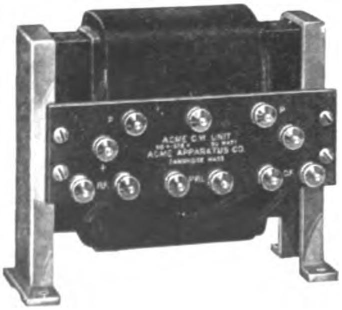

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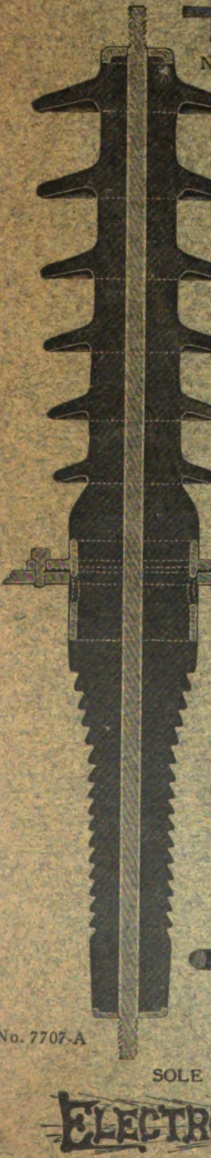
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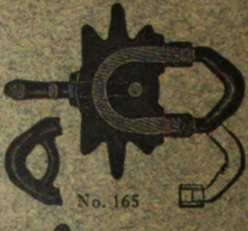
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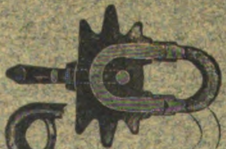
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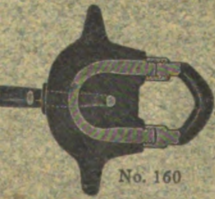
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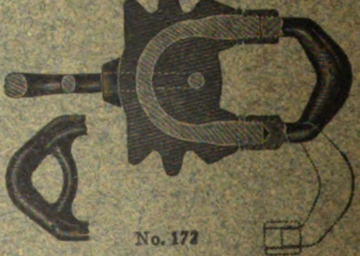
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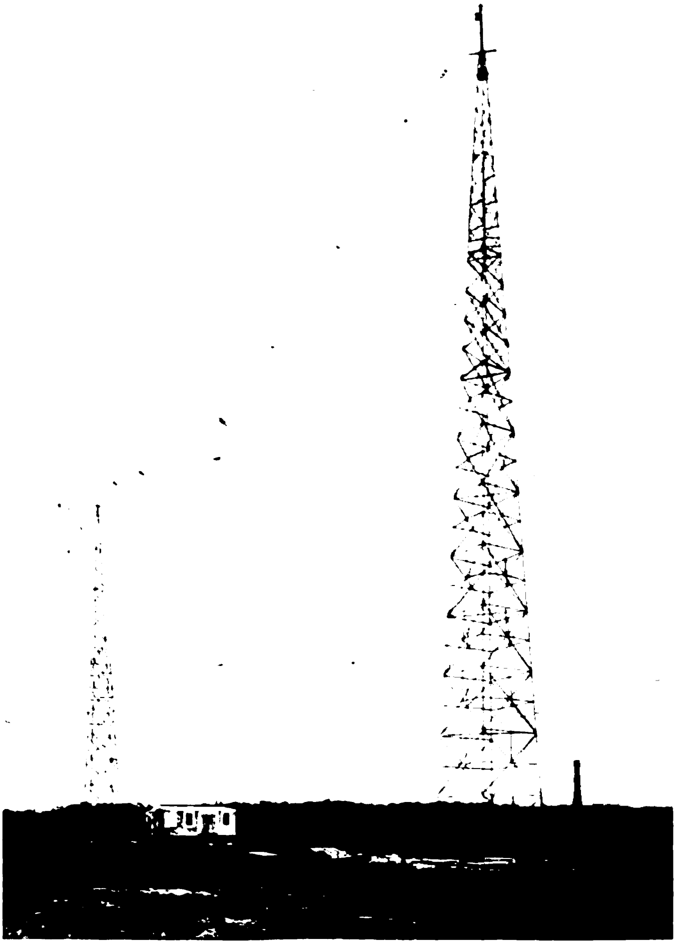

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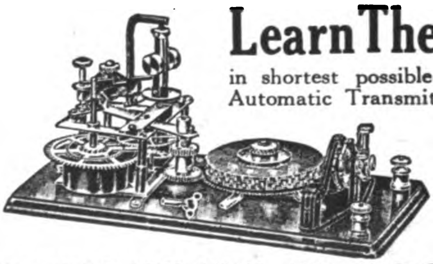

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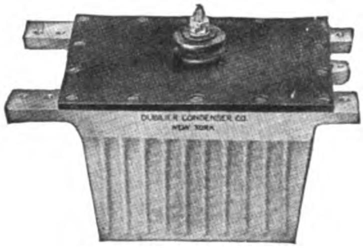

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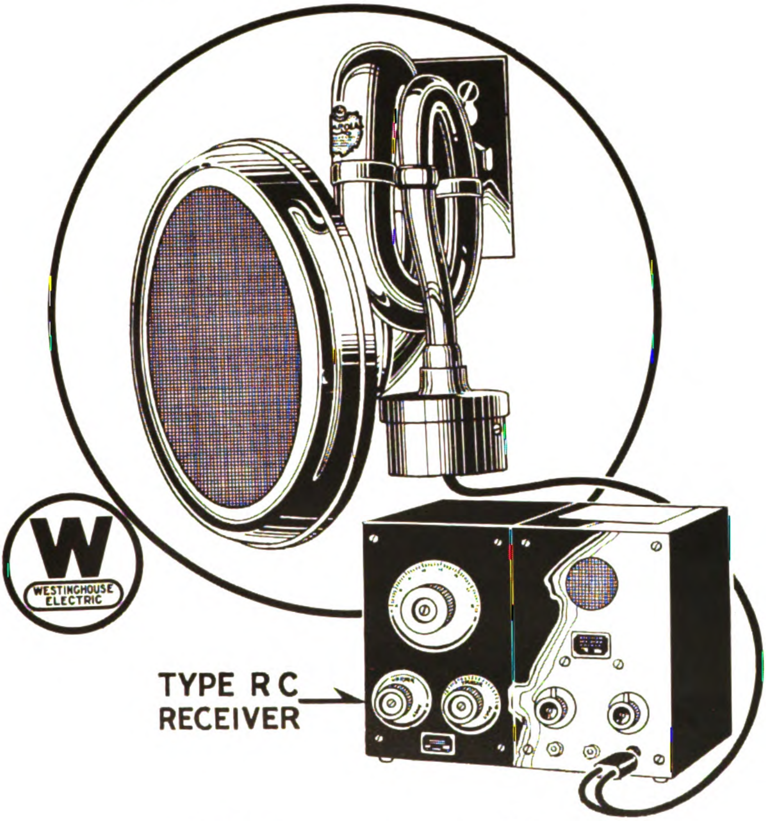

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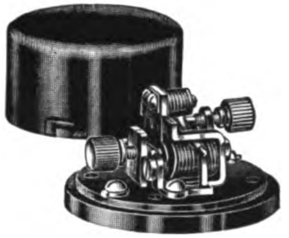

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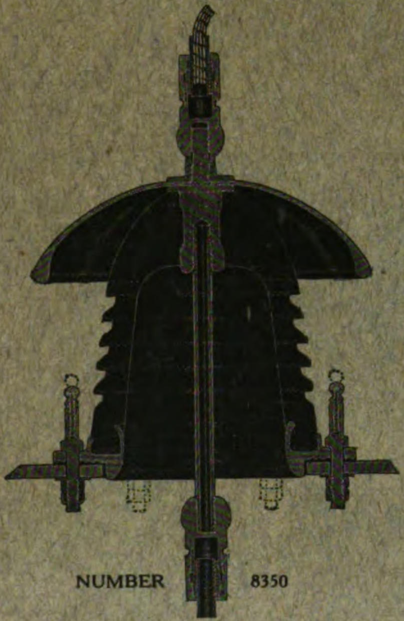

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